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The Journal of Bone and Joint Surgery

The Official Publication of

The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand

OCTOBER 1950

American Volume

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The Journal of
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American Volume

SURGICAL TREATMENT OF FRESH INJURIES TO THE MAJOR LIGAMENTS OF THE KNEE *

BY DON H. O'DONOGHUE, M.D., OKLAHOMA CITY, OKLAHOMA

*From the Department of Orthopaedic Surgery and Fractures,
University of Oklahoma School of Medicine*

For many years the author has had the privilege of attending to the major injuries of a large number of athletes, not only of college, but also of high-school age. None are so pleasant to treat and so eager to get back to the fray as these students. It is a problem to keep them from recovering too soon for their own good. One is forced then to seek methods which aim at obtaining the maximum recovery in the minimum time. The degree of recovery must always be paramount, but the rapidity of the cure cannot be ignored.

Only one goal is permissible in the care of the young athlete,—namely, complete recovery; for, in the majority of cases of severe injury, especially to the knee, if the recovery is not complete, the patient is no longer an athlete.

These principles apply to all major injuries. One particular injury which apparently has not received excellent, or even very good, treatment throughout the years is that injury caused primarily by abduction and external rotation of the tibia on the femur, with that unhappy triad (1) rupture of the medial collateral ligament, (2) damage to the medial meniscus, and (3) rupture of the anterior cruciate ligament. While there are many other types of injury to the knee and to other joints common in athletes, this paper deals entirely with this injury in its various degrees.

In a rather careful review of the recent literature, one is impressed by the great number of articles directed toward management of meniscus injury. Relatively few have written in any detail concerning major ligament injury, a notable exception being the report to this Academy in 1943 by Abbott, Saunders, Bost, and Anderson. Brantigan and Voshell in their meticulous description of the function of the various structures of the knee have pointed out many valuable concepts in regard to the inter-relation of the various joint structures. However, their work has been widely misunderstood and often misquoted because of too casual interpretation of their conclusions. While it is true that both the anterior cruciate and the medial collateral ligaments prevent abduction-external rotation of the tibia and, with either intact, this motion may be checked, obviously, with both intact, the *strength* of the check is greater. If two of the five stabilizing factors of the knee are disrupted and *one* is repaired, improvement is noted; but, if *both* are repaired, the chance of improving stability and strength is greatly enhanced. Then, too, the greatest stability is in complete extension, in which position several stabilizing elements may be impaired without appreciable increase of motion. The athlete, however, must have stability in moderate flexion, where stability requires that *all* the structures be efficient.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 16, 1950.

The time to diagnose an injury to the knee is at the time of injury. How often have we seen the athlete hobble from the field, be checked by the trainer or physician, and be put to bed with ice caps on the knee to await a more convenient time for a more leisurely examination! Far too often that examination is not made until weeks later, when manifest instability and disability demand that something be done. In too many instances the golden opportunity has passed, and *reconstruction* instead of *repair* must be undertaken with a resulting loss of time, increase in the extent of surgery, and impairment of the chances for that complete success which so frequently follows prompt, early, meticulous repair of every damaged structure.

Immediately after injury, a careful examination can be done with an ease not possible later, since muscle spasm has not supervened, initial local shock has dulled the pain, and swelling and hemarthrosis have not yet developed. At this time careful, tender examination will reveal with surprising accuracy: (1) the degree of lateral instability, which is a valuable guide to the *extent* of the damage to the medial collateral ligament; (2) the exact area of tenderness, which serves to indicate the *location* of the tear or tears; (3) the positive drawer sign, which relates to the integrity of the anterior cruciate ligament; and (4) the restriction of extension which, if present early, before muscle spasm, is an almost infallible sign of meniscus damage. Careful attention to these four findings will often permit diagnosis of a serious ligament injury, even in that patient who has walked from the field with an apparently minor disability. While later, hemarthrosis, local swelling, and pain may be significant in indicating the *severity* of the injury, they are not especially diagnostic as to the *type* of the injury.

Granted that one cannot always see these patients early, a determined effort to have them sent in early will yield excellent cooperation on the part of the team physician or trainer. This is particularly true if the orthopaedist sets a good example by prompt attention, even at some inconvenience to himself. The habit of seeing Saturday's injuries on Monday is not conducive to early diagnosis and prompt definitive treatment.

An early decision as to treatment must be made immediately after examination. *Surgery should not be reserved for those cases in which conservative treatment has failed.* Modern asepsis, improved anaesthesia, and chemotherapy have minimized the hazards of surgical procedures to the degree that, in a well-run hospital with a competent surgical team, open surgery on a joint injury can take its place alongside non-surgical methods. The selection of treatment, in the absence of complicating factors, hinges on a decision as to what method will give the most complete recovery in the shortest time. The shorter the period of interference with normal joint mechanics, the more rapid and complete will be the recovery.

The knee which demonstrates a serious or complete rupture of the medial collateral ligament, a fracture of the medial meniscus, or a tear in the cruciate ligament, or any combination of these, should have early and careful repair not of one or two, but of all damaged structures. Both superficial and deep layers of the collateral ligament must be replaced and repaired, the damaged or displaced meniscus must be removed, and the cruciate ligament must be repaired or plicated. Repair of the cruciate ligament should not be omitted because it "adds to the severity of the operation", or "may not be essential". By early exposure, one can clearly define *all* the damage and repair it all; only by complete repair of *all* structures will these injuries show maximum recovery. Complete recovery must be the goal in every case. In some instances, an apparently perfect result will follow incomplete repair. In other instances, imperfect results may follow apparently complete repair. However, by striving for complete repair in all cases, the proportion of normal results becomes higher.

Some authors have described brilliant results from non-surgical treatment of major ligament injuries. Their follow-up seems to indicate good stable knees. It is, however, difficult for the author to reconcile these results with his own observations.

His findings in various cases have shown the medial collateral ligament with its torn end lying within the joint; the semitendinosus, as well as the sartorious tendon end lying free and retracted; the collateral ligament avulsed from the tibia and retracted as far as one and one-half to two inches; the superficial layer of the ligament avulsed from the tibia and the deep layer from the femur, and *vice versa*; the meniscus entirely loose except for its attachment at the two ends; or the ligament folded up and lying under the cartilage. However, it has been impossible to determine accurately before surgery just which of these situations was present. How can one determine in advance which case will give a satisfactory result by simple plaster fixation? If one waits to see, at best he has lost the optimum time for surgery; at worst, he has precluded the possibility of success by surgery.

Routine x-rays of these injuries will be non-productive, unless certain precautions are taken. A single flat anteroposterior roentgenogram should be followed by one made with the leg slightly flexed and forcibly abducted. If done *early*, this readily shows the "opening up" of the medial joint space (Fig. 7). If not conclusive, the opposite limb should be x-rayed. After the patient is asleep, study of the range of abduction of both legs may be instructive. However, the lateral "rocking" of the leg is usually so definite clinically that, if the roentgenograms are positive, so will be the clinical check of motion.

PATHOLOGICAL ANATOMY

Most anatomical descriptions of the medial ligament of the knee are somewhat obscure and inaccurate from a functional point of view. Since this has been accurately pointed out by others—notably, Brantigan and Voshell; Abbott, Saunders, Bost, and Anderson—it needs no detailed description here. However, these latter descriptions seem needlessly complicated in consideration of early repair of the ligament. The important thing to remember is that there are two distinct layers of the medial collateral ligament (Fig. 1). The superficial long fibers arise from the region of the epicondyle of the femur to attach well down on the tibia, some one and one-half to two inches below the rim of the tibial condyle. The upper portion of this ligament blends with the vaginal fascia of the thigh and the muscle fascia of the lower thigh. The deep layer consists of short, thick fibers passing in several directions and in several groupings, but basically connecting the rim of the femoral condyle to the upper rim of the tibia. While these two layers may seem intimately blended, that they are essentially separate is indicated by the fact that they almost invariably tear at different levels.

In considering repair, it is essential to inspect both layers, since a major tear in the deep layer may well be, in fact usually is, screened by the superficial layer (Fig. 2). By far the most common location of the tear in the superficial layer is at its tibial insertion and may often consist in an apparent slipping or stripping of the fibers from the tibia. The upper attachment is infrequently torn since, as has been previously noted, it has a connection to the muscle fascia of the thigh and so has a certain amount of elasticity. It is necessary to separate this layer from the tibia and to retract it upward to expose the deep layer, which may be torn from the femur, or from the tibia, or between the two (Fig. 3). Often a single case may show the deep ligament torn from the tibia in front, and torn from its femoral attachment in its posterior portion, or *vice versa*, with a tear through the ligament in the central portion. It is the deep layer which includes the attachment of the meniscus.

Thus, the meniscus will remain with the tibia, if the femoral attachment is torn, and may be wholly undamaged. However, if the central part of the ligament is torn or if the tibial attachment is pulled away, the meniscus is usually displaced and often ruptured.

The importance, surgically, of these facts is that the surgeon must be sure that he has found *and repaired* each tear, and not be satisfied with a superficial repair. The meniscus must be carefully analyzed as to the integrity of its attachment, both anteriorly and posteriorly.

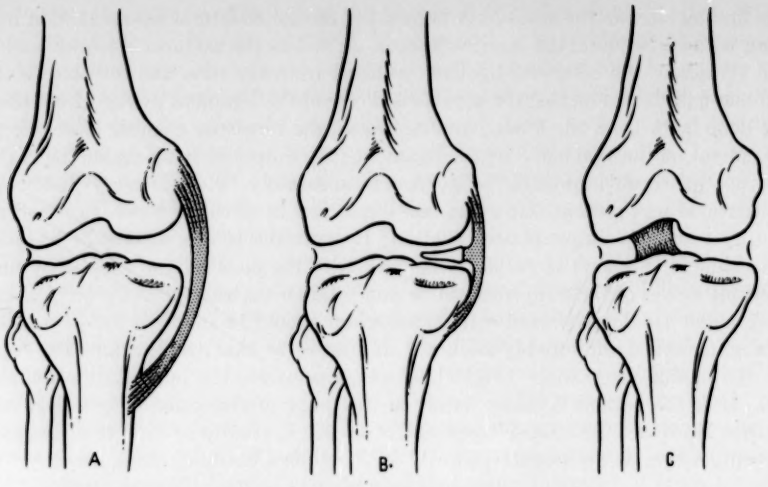

FIG. 1

Ligaments subject to injury
A: Superficial layer of medial collateral ligament.
B: Deep layer of medial collateral ligament with medial meniscus attached.
C: Anterior cruciate ligament.

The anatomy of the cruciate ligament has been ably described by Brantigan and Voshell, Palmer, and others. There is some difference of opinion as to the exact function of this ligament. Obviously, to retain this function, whatever it is, the ligament must be carefully inspected and, if damaged, must be repaired. The most consistent positive finding in injury to this ligament is the positive "drawer sign". If this is present, as compared with the opposite knee, it must be assumed that the ligament is stretched or torn, and it must be plicated or repaired.

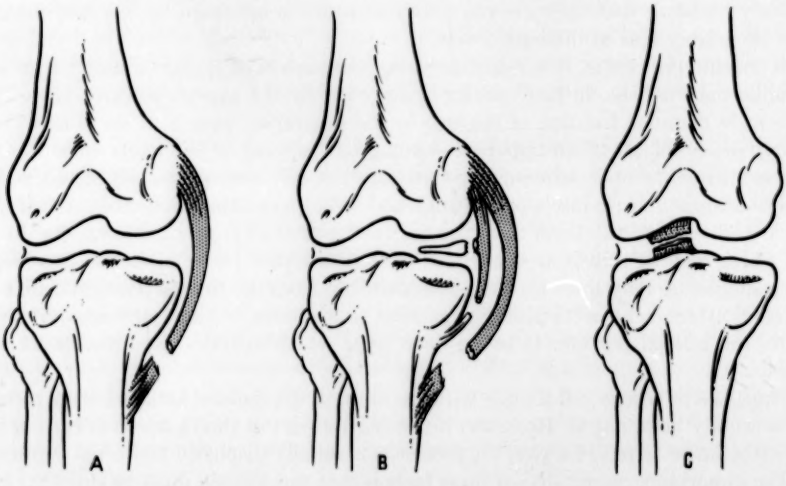

FIG. 2

Typical injuries to knee
A: Tear of superficial layer of the medial collateral ligament.
B: Tear of deep layer with medial meniscus detached. *C:* Tear of anterior cruciate ligament.

FIG. 3

"The unhappy triad": Tear of superficial layer of medial collateral ligament; tear of deep layer of the ligament and of the medial meniscus; tear of anterior cruciate ligament.

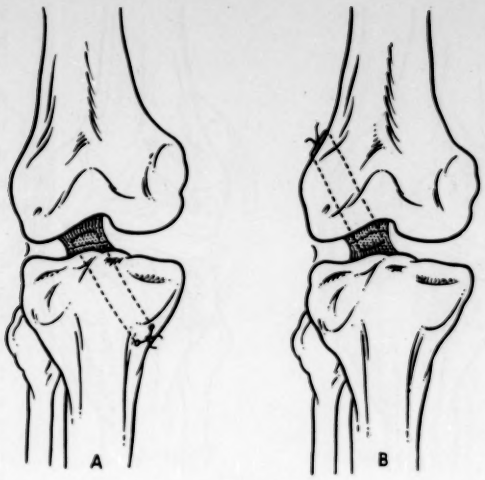

FIG. 4

Repair of anterior cruciate ligament
A: Drill holes through tibia permit passage of suture to secure detached ligament to tibia.
B: Similar method to secure proximal end to the femur.

THE OPERATION

While no new operative procedures are presented here, a few words as to the *technique* of repair may serve to clarify the *intent* of repair.

Access to the area is obtained through a flat lazy-S incision, beginning well above the femoral epicondyle anteromedially, and crossing the anteromedial aspect of the joint to end about three inches below the tibial rim along its anteromedial surface. This gives access to the entire medial aspect of the knee.

The superficial layer of the ligament is revealed and inspected. The site of damage

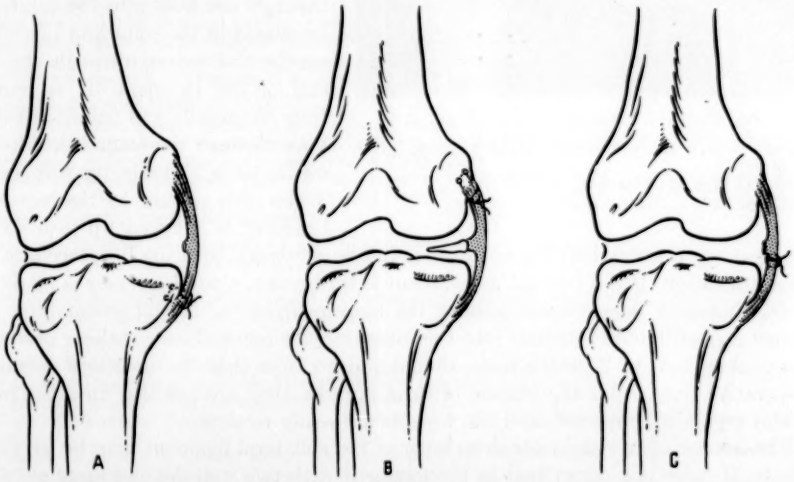

FIG. 5

Repair of deep layer of medial collateral ligament
A: Repaired by suture to tibial margin through drill holes.
B: Repaired by suture to femoral condyle through drill holes.
C: Simple suture of torn ends of ligament.

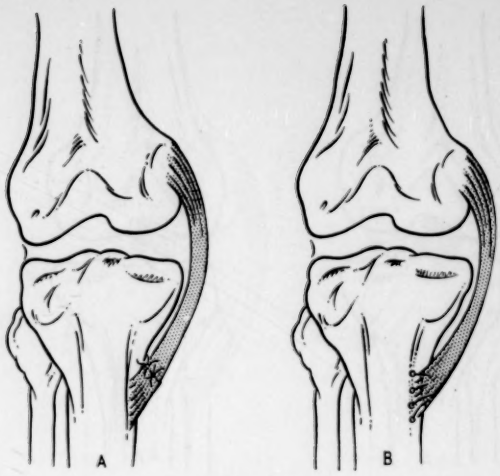

FIG. 6

Repair of superficial layer of medial collateral ligament.
A: Suture of torn end of ligament to stump.
B: Repair of avulsed end by suture through drill holes in tibia.

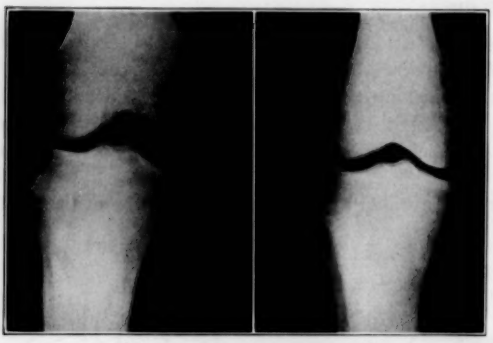

FIG. 7

Typical x-rays taken without patient being given anaesthetic.
A: With the tibia in abduction.
B: With the tibia in neutral position.

will be indicated by ecchymosis and hematoma within the fibers, usually at its tibial attachment. This may be demonstrated also by rocking the tibia on the femur. The tear is defined, by sharp dissection if necessary, and the superficial layer is retracted to expose the deep layer.

This layer must be inspected entirely across the line of the joint from front to back, and again rocking the tibia may give a clue as to the site of the tear. This tear is readily seen, if the operation is done before healing occurs. Frequently, the ligament will be torn in an irregular fashion,—that is, from the femur in front, across the joint, to the tibial attachment behind, or *vice versa*. It is advisable at this stage to enter the knee by an incision through the capsule along the medial parapatellar line. Through this incision, the medial meniscus is exposed; and decision as to its removal is made and carried out. The anterior cruciate ligament is inspected. If torn from the tibia, two drill holes are passed from the anteromedial surface of the tibia into the area of the anterior spine (Fig. 4). A suitable ligature (No. 3 twisted silk or No. 10 cotton) is passed through one hole into the joint. It is recovered in the joint and placed in a needle and woven through the loose end of the ligament. It is removed from the needle and passed out of the knee through the second drill hole by means of a suitable ligature carrier. When this suture is tightened, the ligament is snugged up into its bed. If the ligament is redundant but not torn, it can be shortened by a similar procedure after some scarification. If the femoral attachment is torn away, a similar repair is made with two drill holes, in this instance passing the ligature from the lateral epicondylar ridge (through a small lateral incision) into the intercondylar notch. None of these procedures is formidable; and, with proper tools, should add no more than ten or fifteen minutes to the operative time. After the placing of these sutures, they are not tied until the medial ligament repair is completed, and the wounds are ready to close.

The immediate repair of the deep layer of the collateral ligament may be by various methods. If there is a direct tear in the ligament with two well defined margins, simple suture will suffice, with imbrication if feasible (Fig. 5). If the ligament is avulsed from bone, the best method of repair consists of a series of three or four superficial drill holes at the attachment, about three-quarters of an inch apart. Suitable suture is passed through

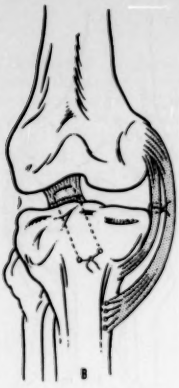

FIG. 8

Case 1

A: The injury *B:* The repair

FIG. 9

Case 2

A: The injury *B:* The repair

CASE 1, J. B., white male, nineteen years old.

History: On December 3, 1938, while playing college football, was hit on the side of the knee, with immediate pain and disability.

Examination a few hours later revealed marked lateral instability, hemarthrosis, positive drawer sign, and tenderness over the tibial attachment of the medial collateral ligament.

Operation December 3, 1938:

Findings: Superficial layer of the medial ligament was torn loose from the tibia; deep layer was torn near its tibial attachment; medial meniscus was detached; and anterior cruciate was torn from the tibia.

Repair: Anterior cruciate was repaired by suture to the tibia through drill holes. Medial meniscus was removed. Repair of the deep layer of medial ligament by suture to its stump. Repair of the superficial layer by suture to the tibia through drill holes.

Course: In plaster for eight weeks; then used brace for six weeks. Three months after operation, knee seemed normal except for a nodule where the drill hole had been made in the tibia.

Result: Complete recovery, four months after operation (played forty holes of golf). Nine months after operation, normal appearing knee with no restriction of motion and no instability; playing football without complaint. Ten years after operation, normal knee.

CASES 2 and 3, L. G. F.

History (left knee): On March 21, 1939, while playing football, was struck from the side, with immediate pain and disability and locking of left knee (Fig. 9).

Examination on March 22, 1939, showed effusion, swelling, tenderness at the tibial attachment of the medial collateral ligament, with restriction of extension of the knee. Drawer sign was negative. Lateral instability was questionable because of muscle spasm.

Operation March 23, 1939:

Findings: Torn medial meniscus; laceration of medial collateral ligament; superficial layer had slipped on its attachment to the tibia. Deep layer was partially torn from the tibia. Lateral instability was evident under anaesthesia. Cruciate ligament was intact.

Repair: Medial meniscus was removed. Both layers of the medial ligament were repaired by suture.

Course: In plaster for one month. Two months later, apparently normal left knee. Played college football before six months had elapsed.

History (right knee): On November 4, 1939, injured the opposite knee, while playing college football. He felt that "the knee was bent sideways". Knee was not locked. Ice packs were used for forty-eight hours.

Examination November 6, 1939 revealed mild effusion, tenderness over the tibial attachment of the medial ligament. So-called "conservative treatment" was used for four weeks. Lateral instability became very evident at this time, as pain subsided.

Operation November 30, 1939:

Findings: Torn medial meniscus. Medial collateral ligament was intact. Anterior cruciate ligament was partially avulsed from the tibia. Negative drawer sign.

Repair: The medial meniscus was removed. No repair to the cruciate ligament or to the collateral ligament.

Course: In plaster for twelve weeks. Three months later, he had normal motion, no instability, negative drawer sign, pain in the knee on "snap extension".

Result: Ten months after operation, he was playing college football. No complaint whatever of the *left* knee. He had trouble with the *right* knee on forced extension.

Comment: The completely repaired *left* knee, which was the more seriously injured, went on to an entirely complete recovery. Because of inadequate repair, the *right* knee, which had the lesser injury, required a longer convalescence and continued to bother him.

FIG. 10

Case 4

A: The injury *B:* The repair

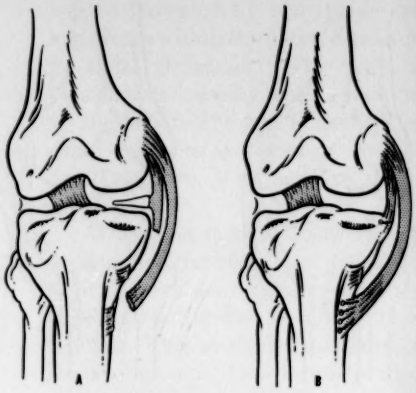

FIG. 11

Case 6

A: The injury *B:* The repair

CASES 4 and 5, D. W., white male, nineteen years old.

History (right knee): On September 23, 1942, while playing college football, he was tackled from the side, while going up for a punt. Was injured on the *right* knee with immediate pain and disability and inability to straighten the knee (Fig. 10).

Examination on same day showed hemarthrosis, questionable drawer sign, definite lateral instability of the knee, and tenderness over the tibial attachment of the medial collateral ligament and over the medial meniscus.

Operation September 25, 1942:

Findings: Both layers of the medial collateral ligament were torn from the tibia. Medial meniscus was entirely free from the tibia and from the medial ligament. Anterior cruciate was avulsed from the tibia.

Repair: Cruciate ligament was repaired by suture through drill holes through the tibia. The medial meniscus was removed. Superficial and deep layers of the medial ligament were repaired by suture through drill holes in the tibia.

Course: Plaster fixation for seven weeks followed by rehabilitation by ordinary measures. On March 8, 1943, six months after operation, he passed examination for officer in the Air Corps. Examination then revealed no lateral instability, negative drawer sign, 15 degrees of restriction of flexion. He played football in the Army for several years. Later he played college football for two years, with no complaint whatever.

Result: Seven years after operation, normal appearing knee with normal range of motion and no instability.

History (left knee): On March 10, 1947, same patient received an injury to the *left* (opposite) knee, followed by pain, swelling, and disability. Negative drawer sign and no lateral instability.

Operation March 11, 1947:

Findings: Bucket-handle tear of the medial meniscus with frayed anterior attachment of the anterior cruciate ligament, but without loss of continuity of the ligament.

Repair: Medial meniscus was removed and cruciate-ligament ends were trimmed away.

Course: Splint was used for two weeks, followed by elastic bandage and rehabilitation. Six months after operation, he was running, and the left knee "slipped forward on him". It did not lock. He said that he had pain "all over the knee", and the knee felt weak. He was continually afraid the knee was going to slip forward and he had to walk carefully.

Result: This *left* knee has never entirely recovered. He continues to have pain on extension of the knee, but there is no lateral instability. He has a feeling that the tibia will slip forward on the femur when he is running and tries to stop.

Comment: This patient had a good result following the severe injury to the *right* knee which had a complete repair. The result in the *left* knee with the lesser injury probably would have been better had the cruciate ligament been repaired at the time of original surgery.

CASE 6, R. P., white male, sixteen years old.

History: In November 1946, boy was playing high-school football and was blocked from the side, forcing the knee in. Knee "slipped out and back". Was in cast for ten days. Recovered sufficiently to play some basketball, although his knee continued to bother him. In May 1947, he was tackled from behind, and the knee slipped out again. Was in a cast three or four days. Complaint was that the knee "is loose and flops sideways" and felt insecure.

Examination June 7, 1947, about six weeks following his last injury, showed drawer sign questionable, definite lateral instability, relaxation of the medial collateral ligament, with pain on abduction of the leg, either flexed or extended. Knee "opened up" medially.

CASE 6 (*Continued*)

Operation June 10, 1947:

Findings: Both layers of the medial collateral ligament were torn loose from the tibial attachment. Medial meniscus was detached; the anterior cruciate was intact.

Repair: Medial meniscus was removed. Superficial layer of the deep ligament was dissected up, permitting repair of the deep layer by suture through drill holes to the tibia. Superficial layer was then repaired by suture through drill holes in the tibia.

Course: Plaster splints were used for four weeks; then weight-bearing was allowed in cotton cast, for two weeks, followed by elastic bandage. General progress was excellent. He played football, as halfback in 1947–1948 in high school; and in 1949 as college freshman.

Result: Examination October 1949, showed knee apparently entirely normal, completely stable laterally, with drawer sign negative, and no restriction of motion.

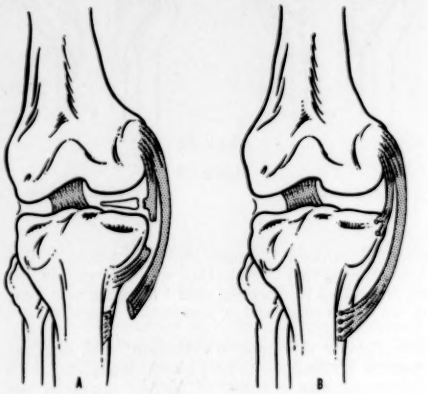

FIG. 12

Case 7

A: The injury *B:* The repair

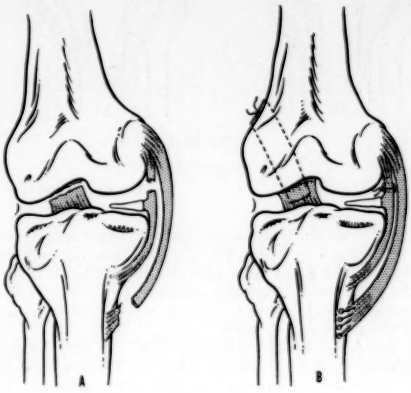

FIG. 13

Case 8

A: The injury *B:* The repair

CASE 7, F. A., white male, eighteen years old.

History: Patient had had episodes of knee-locking on three occasions, beginning three months before. On December 21, 1946, while playing football, he was hit on the medial side of the knee with immediate pain, swelling, disability, and restriction of motion.

Examination December 23, 1946, showed marked swelling of the knee with effusion, tenderness over the upper medial portion of the tibia, negative drawer sign, and marked lateral instability in extension or in flexion.

Operation December 27, 1946:

Findings: Superficial layer of the ligament was avulsed from the tibia; deep layer was avulsed from the tibial rim; and medial meniscus was completely loose except for anterior and posterior attachments. Anterior cruciate ligament was intact.

Repair: Medial meniscus was removed; deep layer and superficial layer of the ligament were repaired by suture to the tibia through drill holes.

Course: Extremity was immobilized for five weeks, followed by rehabilitation of the knee. Three months after operation, patient had practically normal range of motion and complete stability; there was still some effusion. Twelve months after operation, knee appeared to be entirely normal.

Result: Three years after operation knee was apparently normal, with no restriction of motion and no instability. He played end in championship college football, 1947, 1948, and 1949.

CASE 8, N. M., white male, twenty-two years old.

History: In New Year's game, was blocked on the outer side of the right knee with immediate disability, pain, swelling, and inability to bear weight. Knee was treated by cold packs and support.

Examination January 4, 1947, revealed marked swelling and effusion, tenderness over the medial, upper portion of the tibia, relaxation of the medial collateral ligament, and positive drawer sign.

Operation January 6, 1947:

Findings: Superficial layer of the medial ligament was avulsed from the tibia; deep layer was torn at the joint line above the medial meniscus; and medial meniscus was attached to deep layer. Anterior cruciate was torn from the femur.

Repair: Anterior cruciate ligament was attached to the femur through drill holes; deep layer of the medial ligament was sutured at its line of laceration; the medial meniscus was left in place; and the superficial layer was sutured to its torn attachment.

Course: Patient was in a cast for four weeks; used walking splint for two weeks; general rehabilitation of the knee followed.

Result: Normal-appearing knee. Patient has played three years of championship football, was All-American player in 1948.

Comment: The medial meniscus probably should have been removed; however, in this case, it remained attached to the intact distal tibial attachment of the ligament and has given no trouble.

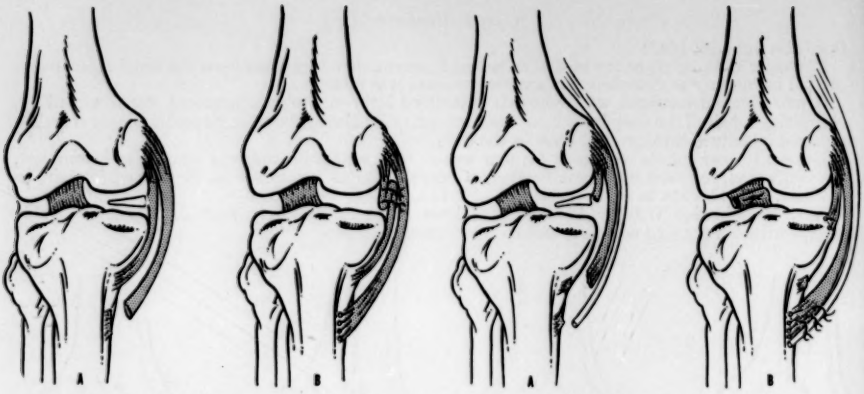

FIG. 14

Case 9

A: The injury *B:* The repair

FIG. 15

Case 10

A: The injury *B:* The repair

CASE 9, J. B., white male, twenty years old.

History: On September 12, 1947, was clipped from behind, injuring the right knee; the whole leg was numb, with immediate pain and disability. Within a week the leg was all right but, while he was playing the next week, a similar accident occurred. Following these two injuries, he said "his knee was loose sideways and he had to keep it taped"; when he got down it was weak and he was unable to get up, but it did not catch or lock.

Examination December 2, 1947, showed the knee was stable in complete extension, with negative drawer sign, and pain on external rotation and abduction. In flexion, he had lateral instability with redundancy of the medial collateral ligament. The diagnosis was a ruptured medial meniscus and medial ligament.

Operation December 30, 1947:

Findings: Medial meniscus was detached; superficial layer of the medial collateral ligament was redundant and detached from its tibial attachment; the deep layer was also redundant and had definite increase in length; the cruciate ligaments were intact.

Repair: Deep layer of the collateral ligament was plicated; superficial layer was overlapped and sutured down to the tibial stump through drill holes. Medial meniscus was removed.

Course: Extremity was in splints for four weeks. Two and a half months later, patient was in a car accident and injured the knee so that it swelled again, but its stability was not affected. The knee was entirely stable laterally.

Result: Two years after operation he had no pain, no instability, no restriction of motion, and knee was entirely stable in all positions. He had been playing basketball, baseball, and football.

Comment: This case is a little unusual in that its repair was done three months after injury. While it probably would have been much better had it been repaired early, the case does show that late repair can give good results, particularly if it is not *too late.*

CASE 10, J. T., white male, twenty-four years old.

History: October 11, 1947, while playing college football, was hit from the front and side, and knee was bent backward, with immediate disability. He was placed at bed rest with ice packs.

Examination October 13, 1947, showed tenderness over the medial upper portion of the tibia, marked lateral instability, questionable increase in drawer sign, and severe swelling and effusion of the knee.

Operation October 14, 1947:

Findings: Superficial layer and deep layer of the medial collateral ligament, and the semitendinosus tendon were avulsed from the tibial attachment. Medial meniscus was torn loose at the anterior end, and the anterior cruciate ligament was relaxed and injected.

Repair: Medial meniscus was removed; deep layer of the medial collateral ligament was sutured to the tibia through drill holes, the superficial layer and the tendon were attached through drill holes, and the anterior cruciate ligament was plicated through drill holes.

Course: Was in plaster for four weeks, and then elastic bandage was used for two weeks, with rapid and good rehabilitation.

Result: Played football six months after operation with an entirely stable knee. Examination two years later revealed no instability, no pain, no restriction of motion, no complaint of any kind. Played championship college football, 1948; professional football, 1949.

the ligament ends, into one drill hole, out of an adjacent drill hole, and back through the ligament. When all of these have been placed, the knee is positioned at about 150 to 160 degrees and all ligatures are tied. As a rule, the superficial layer can be repaired by simple suture to its bed. If not, a similar procedure may be carried out by drill holes at this level

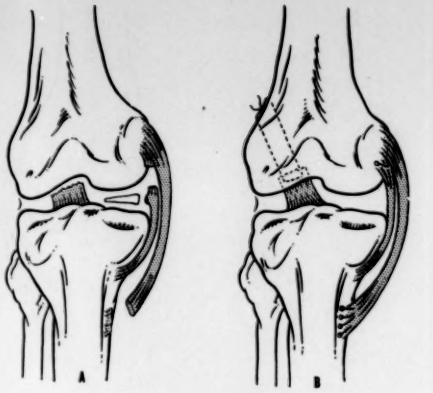

FIG. 16
Case 11
A: The injury *B:* The repair

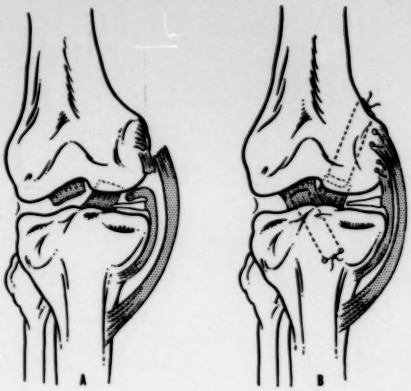

FIG. 17
Case 12
A: The injury *B:* The repair

CASE 11, L. M., white male, twenty years old.

History: On March 31, 1948, was scrimmaging in spring practice. He was blocked from the side, forcing his knee inward, with the foot in external rotation. The local doctor found the knee unstable laterally.

Examination April 2, 1948, revealed complete loss of integrity of the medial collateral ligament with marked lateral instability. Knee could be "opened up" medially. Positive drawer sign was present, with marked swelling, hemarthrosis, tenderness along the upper medial portion of the tibia, and pain on attempted motion of the knee.

Operation April 2, 1948:

Findings: Superficial layer of the medial ligament was avulsed from the tibia; deep layer of the ligament was avulsed from the femur; medial meniscus was detached; anterior cruciate ligament was detached from the femur, and there was marked instability of the knee.

Repair: Cruciate ligament and deep layer were attached to the femur through drill holes; superficial layer was sutured to tibia through drill holes.

Course: In splints for four weeks, elastic bandage for four weeks. At six weeks after operation, knee was entirely stable, and drawer sign was negative.

Result: Fifteen months after operation, knee was entirely stable, with no restriction of motion, strong extension, negative drawer sign, and restriction of 10 degrees in flexion. Returned to championship football after one year.

CASE 12, B. L., white male, twenty years old.

History: On September 6, 1948, was blocked from the side, forcing the knee inward. His knee "slipped out" and the trainer reduced it; x-ray was made and a cast was applied.

Examination September 10, 1948, revealed marked swelling of the knee with effusion, definite lateral instability, drawer sign questionable, tenderness over the upper portion of the tibia, and restriction of flexion due to the effusion.

Operation September 14, 1948:

Findings: Both layers of the medial collateral ligament were torn off the femur, leaving a bare femoral condyle. The posterior cruciate ligament was torn off the femur; the anterior cruciate was torn off the tibia; and the medial meniscus was intact.

Repair: The posterior cruciate was attached to the femur through drill holes, and the anterior cruciate was attached to the tibia through drill holes. The deep layer and the superficial layer of the medial collateral ligament were sutured to the medial femoral condyle through drill holes. This ligament was badly torn and was reinforced by a fascia lata strip, covering the whole medial aspect of the knee.

Course: Extremity was kept in plaster for four weeks, in cotton cast for two weeks; rehabilitation of the knee followed.

Result: One year later, had a completely stable knee, with no restriction of motion and negative drawer sign. He has some discomfort at the site of the removal of the fascia lata, where there is bulging of muscle through the defect.

Comment: This athlete is a champion high jumper in collegiate competition. He "takes off" from this leg, which would not be possible with anything less than a normally functioning knee.

(Fig. 6). General imbrication of the ligament by suture may be done to obtain maximum tightness.

While these procedures may seem somewhat formidable, the experienced surgeon

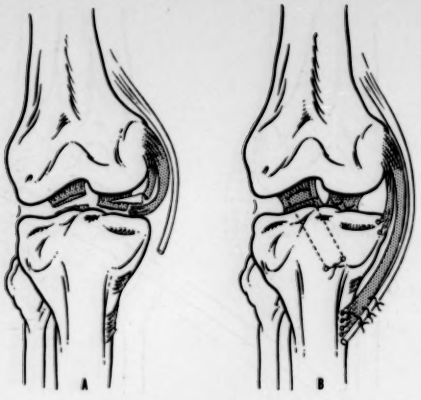

FIG. 18

Case 13

A: The injury *B:* The repair

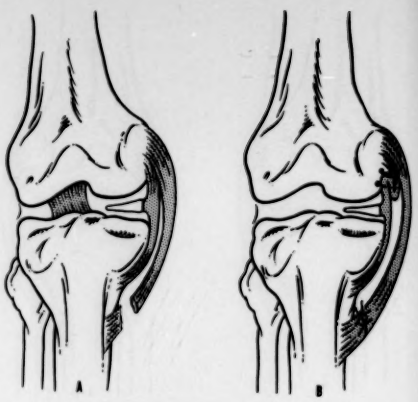

FIG. 19

Case 14

A: The injury *B:* The repair

CASE 13, L. N., white male, twenty-four years old.

History: On October 1, 1948, while playing college football, was hit on the side of the knee with immediate disability.

Examination on same day revealed severe injury to the knee with complete loss of function of the medial collateral ligament, tenderness and swelling over the tibial attachment of the ligament, and positive drawer sign. Knee was swollen with hemarthrosis.

Operation October 2, 1948:

Findings: Superficial layer of the medial collateral ligament and semitendinosus tendon were avulsed from the tibia. Deep layer of the ligament was torn off the tibia, carrying with it the ruptured medial meniscus, which was completely free from the tibia. Anterior cruciate ligament, with a fragment of the tibial spine, and the distal portion of the posterior cruciate ligament were torn off the tibia.

Repair: Medial meniscus was removed; anterior cruciate ligament was reattached to the tibia through drill holes; posterior cruciate ligament was sutured to soft tissue at the posterior lip of the tibia; deep layer of the medial collateral ligament was reattached to the tibia through drill holes; and the superficial layer of this ligament as well as the semitendinosus tendon were sutured to the tibia through drill holes.

Course: Immediate postoperative course was good; patient left hospital in five days; weight-bearing was allowed at four weeks with short splints, which were replaced by elastic bandage at five weeks. At six weeks had recurrence of swelling, pain, and fever,—apparently an infection of knee. Was treated by aspiration, chemotherapy, bed rest, and hot packs. Cultures remained negative. Symptoms subsided after a week or ten days and he slowly regained function of the knee, which remained completely stable, but with restricted motion. On January 1, 1949, three months after operation, motion was normal.

Result: Played college basketball 1948–1949, all-star football in April, 1949, and professional football in 1949. Knee is apparently normal, completely stable, with negative drawer sign and normal motion.

Comment: This patient had a stormy course, following a secondary reaction, apparently from some systemic infection. In spite of this, he regained normal function.

CASE 14, E. M., white male, sixteen years old.

History: On October 9, 1948, while playing high-school football, with the knee a little flexed, was hit from the side. Immediate pain, disability, and swelling resulted.

Examination on October 10, 1948, revealed mild hemarthrosis; negative drawer sign; and normal motion. Knee was stable in extension; there was increased lateral instability with the knee semiflexed, and tenderness over tibial attachment of the superficial portion of the medial collateral ligament. Cast was applied, on the diagnosis of a partial avulsion of the medial collateral ligament. Three weeks later lateral instability was definite in both extension and flexion, and operation was advised.

Operation October 31, 1948:

Findings: Tibial attachment of the superficial layer of the medial collateral ligament had "skidded" away. The deep layer was detached from the femur; medial meniscus was displaced with the deep layer; anterior cruciate ligament was intact.

Repair: The deep layer was reattached to the femur by drill holes; the superficial layer was sutured down to the stump, and the medial meniscus was left in place.

Course: After six weeks in plaster, the knee was stable, although motion was restricted.

Result: Returned fourteen months after operation with knee apparently normal. Played basketball three months after operation, also baseball and football. Would not wear an elastic bandage even when playing football.

Comment: Misguided so-called "conservative" treatment was abandoned in time to obtain good postoperative result.

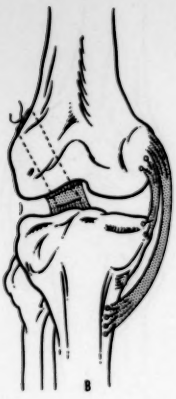

FIG. 20

Case 15

A: The injury *B:* The repair

FIG. 21

Case 16

A: The injury *B:* The repair

CASE 15, L. T., white male, twenty-two years old.

History: While playing football December 12, 1948, was blocked from the outside, with immediate pain, disability, and swelling. Cold packs for twenty-four hours, then hot packs were administered. Fluid was aspirated.

Examination December 14, 1948, revealed marked swelling, pain on the medial aspect of the knee, tenderness along upper, medial portion of tibia, marked lateral instability, and positive drawer sign.

Operation December 15, 1948:

Findings: Superficial layer of the medial collateral ligament was avulsed from the tibia; the deep layer was avulsed from the femur in its anterior one-half, and from the tibia in its posterior one-half in a Z line; the medial one-half of the posterior cruciate ligament was torn from the tibia; the anterior cruciate was torn from the femur, and the medial meniscus was loose.

Repair: Medial meniscus was removed; anterior cruciate ligament was reattached to the femur through drill holes, and the posterior ligament was attached to the posterior tibial margin. The posterior one-half of the deep layer of the medial ligament was sutured to the tibia and the anterior one-half to the femur through drill holes. The superficial layer was sutured to its torn stump.

Course: Was kept in plaster for five weeks; elastic bandage was then used, and general rehabilitation.

Result: Thirteen months after operation, knee was stable, with 10 degrees' restriction of flexion and no pain. Normal activity was possible.

CASE 16, D. M., white male, twenty-three years old.

History: Injured March 11, 1949, while wrestling, received a twisting, falling type of injury, with severe pain, disability, and locking of the knee. The local doctor administered anaesthetic and unlocked the knee; however swelling and pain continued.

Examination March 15, 1949, revealed swelling, hemarthrosis, positive drawer sign, tenderness over the tibial attachment of the medial collateral ligament, and increased lateral instability of the knee.

Operation March 16, 1949:

Findings: The medial meniscus was ruptured; the anterior cruciate ligament was partially avulsed from the tibia and redundant; superficial layer of medial collateral ligament was torn loose from its tibial attachment; and the deep layer was torn from the tibial rim.

Repair: The medial meniscus was removed; anterior cruciate ligament was repaired by drill holes through tibia; and both layers of the medial collateral were repaired through drill holes.

Course: Extremity was in plaster for three weeks. Knee was apparently normal ten weeks after operation.

Result: Ten months after operation, he was wrestling again on college team. Knee was stable, with normal motion, negative drawer sign, and no complaint.

may readily accomplish repair well within the safe margin of tourniquet time (sixty to seventy-five minutes). If not, the tourniquet may be released after the deep ligament repair has progressed well. Fixation is best obtained by heavy posterior and lateral stirrup plaster splints, extending from the toes to high on the thigh, with the knee in extension of about 150 degrees.

The exact time of fixation must vary somewhat according to circumstances. It has been the author's practice in recent years to immobilize in plaster for about four weeks; and to follow this with a so-called cotton cast, or some similar type of dressing, for another two weeks, during which time weight-bearing is permitted. Following removal of the

FIG. 22

Case 17

A: The injury *B:* The repair

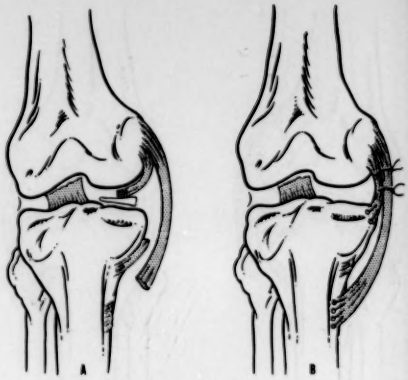

FIG. 23

Case 18

A: The injury *B:* The repair

CASE 17, D. S., white male, eighteen years old.

History: October 15, 1948, while playing junior college football, was hit from the side and his right knee injured. The local doctor applied toe-to-groin cast which the patient had on two months later when the author first saw him.

Examination December 10, 1948, found the knee swollen, extension limited to 160 degrees, drawer sign positive, lateral instability slightly impaired, but no tenderness.

Operation December 12, 1948:

Findings: Medial meniscus was intact; lateral meniscus was split and displaced entirely in front of the femoral condyle; anterior cruciate ligament was avulsed from the femur; there was marked synovitis, and the medial collateral ligament was redundant.

Repair: Lateral meniscus was removed; anterior cruciate was fixed to the femur through drill holes, and the medial collateral ligament was plicated.

Course: Knee was in plaster for five weeks; in cotton cast for two weeks. Two months after operation, drawer sign was slightly positive; flexion was possible to 70 degrees; knee was completely stable laterally; moderate pain.

Result: Nine months after operation there was no lateral instability in extension; slight lateral instability in flexion; slight positive drawer sign; and a feeling of insecurity. Knee was reliable for ordinary pursuits, but not for football. Fourteen months after operation, was improving; desired to play football.

Comment: A late repair with the result too often reported as "good"; is not good enough for the athlete. Early repair should have given a normal knee.

CASE 18, R. McG., white male, nineteen years old.

History: November 20, 1948, received twisting injury to the right knee, when he was tackled from the side, while playing college football. Immediate pain and disability; knee was placed in a cast.

Examination November 21, 1948, revealed marked effusion, pain over the tibial attachment of the medial collateral ligament, pain on hyperextension of the knee. Knee could be "opened up" medially on abduction of the leg with marked lateral instability; positive drawer sign. Diagnosis: ruptured medial collateral ligament; question of rupture of anterior cruciate.

Operation November 22, 1948.

Findings: Both layers of the medial collateral ligament were torn off the tibia; the deep layer was drawn into the knee joint; medial meniscus was loose; and anterior cruciate ligament was torn from its posterior attachment to the femur.

Repair: Medial meniscus was removed; collateral ligament was repaired by drill holes through the tibia, both deep and superficial layers. Cruciate ligament was *not repaired.*

Course: In plaster for eight weeks, then gradual rehabilitation.

Result: Complete stability laterally in any position; positive drawer sign (about twice as much as on the opposite side). He had no pain or restriction of motion, but had a feeling of instability on forcible activity of the knee.

Comment: This patient had a good repair of the medial collateral ligament. His present feeling of the knee slipping forward and backward on forced activity is due to the failure to repair the cruciate ligament. Its instability is sufficient to prevent his playing his position as end in college football. His knee is satisfactory for non-athletic pursuits, but he is no longer an athlete.

protective splinting, six weeks after operation, an elastic bandage may or may not be used, depending upon the effusion within the joint; and the usual measures for rehabilitation following knee surgery are instituted. Quadriceps-setting exercises and exercises designed to maintain the tone of the muscles about the hip and knee may be instituted after the first few days.

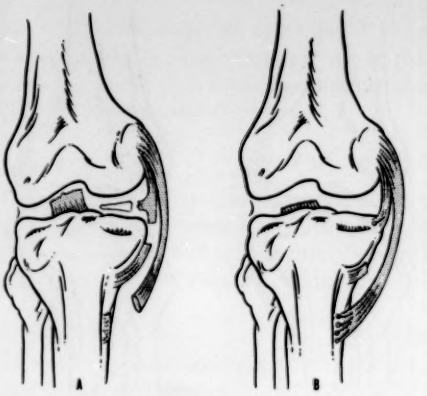

FIG. 24

Case 19

A: The injury *B:* The repair

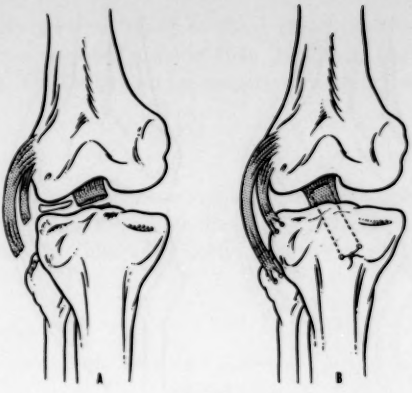

FIG. 25

Case 20

A: The injury *B:* The repair

CASE 19, W. B., white male, thirty years old.

History: August 16, 1948, while playing baseball, slid into the base, injuring his knee.

Examination: Three hours later, the knee "opened up" medially at least one inch. Drawer sign was positive, with pain over the tibial attachment of the medial collateral ligament.

Operation August 19, 1948:

Findings: Superficial attachment of the medial collateral ligament had "slipped loose" from the tibia; the deep layer was detached from the tibia; the posterior attachment of the anterior cruciate ligament was torn from the femur; and there was a posterior tear in the medial meniscus.

Repair: Frayed end of the cruciate ligament was cut away. (Note read, "Impossible to repair it"!) Collateral ligament was plicated and sutured through drill holes, and medial meniscus was removed.

Course: Knee in plaster for one month with the usual rehabilitation over a long period of time.

Result: One year later patient was doing hard work, twelve to fourteen hours a day, loading city warehouse trucks. After about six hours, knee would begin to ache; he had 15 degrees of lateral instability of the knee in flexion, which is definitely an increase over the opposite side; no lateral instability in extension; normal motion of the knee; and positive drawer sign.

Comment: This patient has a useful knee and is entirely satisfied. His pain is diminishing. Although this might be called a "good result", he would not be able to play baseball or other strenuous sports successfully. A more complete repair, including repair of the cruciate ligament, would have increased his chances of having a normally functioning knee.

CASE 20, B. McC., white male, sixteen years old. (This case is presented to show similar injury to the lateral collateral ligament, which is not so common as to the medial.)

History: On September 14, 1945, while tackling another player in high-school football, he got in the "pile-up" and hurt the left knee, with immediate, severe pain. He was unable to move the knee or bear weight; an x-ray taken at home was negative.

Examination September 15, 1945, revealed he had severe pain on both sides of the knee, more severe laterally, just below the line of the joint along the upper margin of the tibia. There was restriction of motion, swelling, hemarthrosis, and lateral instability with relaxation of the lateral ligament. The knee could be opened up laterally; drawer sign was questionable because of pain.

Operation September 24, 1945:

Findings: Avulsion of the lateral ligament from the upper portion of the tibia and from the fibula; separation of the cruciate ligament near its tibial attachment, and fractured lateral meniscus.

Repair: Cruciate ligament was repaired by drill holes through the tibia, and the lateral ligament was repaired by drill holes through the fibula and tibia.

Course: Plaster splints were used for three weeks; cotton cast for one week, and long leg brace for six weeks. After six months, the knee was perfectly strong with no restriction of flexion, although it felt stiff.

Result: Four years after operation, patient was playing professional and college basketball, with no complaint of the knee. Examination shows negative drawer sign, normal motion, complete stability, and apparently a normally functioning knee.

COMMENT

The cases illustrated, if carefully studied, are self-explanatory. Nearly perfect results were obtained in most patients who were seen early, if the diagnosis was accurate and an adequate operation was performed promptly. The second (right) knee in Cases 2 and 3, and the second (left) knee in Cases 4 and 5 illustrate, in the same patients, the different results from complete and incomplete repair. Cases 18 and 19 illustrate technical failure

FIG. 26
Case 21
A: The injury *B:* The repair

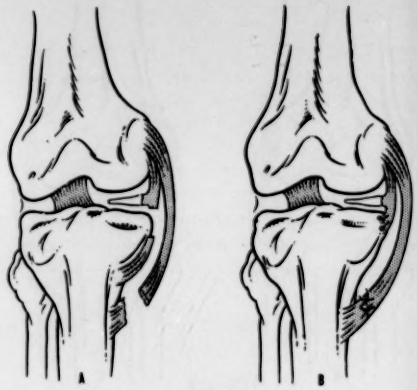

FIG. 27
Case 22
A: The injury *B:* The repair

CASE 21, L. W., negro male, twenty-four years old. (Compensation case for comparison.)

History: On February 17, 1949, was hurt in a ditch cave-in. The knee was forced sideways and "slipped out", with immediate pain and swelling, but he was given no definitive treatment.

Examination March 2, 1949, revealed pain at the anterior end of the medial meniscus, with swelling of the knee, effusion, marked lateral instability of the knee in flexion, and negative drawer sign.

Operation March 4, 1949:

Findings: Both layers of the medial collateral ligament were avulsed from the tibia, including the semitendinosus. The medial meniscus was ruptured; the anterior cruciate ligament was intact, but injected.

Repair: The medial meniscus was removed, the deep layer of the ligament was plicated and sutured, and the superficial layer and the tendon were repaired by drill holes to the tibia.

Course: A typical apprehensive, non-cooperative, compensation patient, making extensive rehabilitation effort very difficult. Was in a plaster cast for three weeks; in a cotton cast for two weeks. Five months later, the knee was stable in extension; there was questionable slight increase in lateral motion in flexion; normal extension; flexion to 70 degrees; negative drawer sign. Patient was disappointed in result.

Comment: Poor rehabilitation, typical of non-athlete. In spite of the favorable age and favorable time of repair, the result was embarrassed by failure of cooperation of the patient.

CASE 22, O. P., white male, forty-two years old. (Compensation case for comparison.)

History: On February 1, 1947, while he was working in an oil derrick, the leg was forcibly abducted on the thigh in an industrial accident. The knee was bent sideways and "popped"; there was no definitive treatment.

Examination February 8, 1947, revealed pain along the medial side of the knee; lateral instability; ability to "open the knee" medially; tenderness along the upper medial portion of the tibia, and drawer sign negative.

Operation February 10, 1947:

Findings: The superficial layer of the medial collateral ligament was avulsed from the tibia; the deep layer was "shredded" from the tibial rim; medial meniscus was firmly attached to the ligament; the anterior cruciate ligament was intact.

Repair: Medial meniscus was left in place; both layers of the ligament were sutured by plication.

Course: Extremity was in cast for five weeks, with knee tight but stiff. Then he was given physical therapy and rehabilitation for three months, achieving a range of motion of 170 to 115 degrees; knee was stable with no pain. Seven months after operation, range was 180 to 60 degrees; knee was stable with no lateral instability; there was pain over the quadriceps tendon on flexion.

Result: Restriction of motion with some complaint; complete stability.

Comment: Age (forty-two) and compensation element were complicating factors in this case. Result was not acceptable for an athlete.

at operation, although proper *decision* for treatment was made. Cases 21 and 22, selected from many "non-athlete" cases, illustrate well the effect of poor rehabilitation, which is often true in compensation cases and in many women. Rehabilitation cannot be delayed for *any* reason. Case 13 was the only case presenting any degree of postoperative infection, including the many cases done within the past twelve months and not reported here. No surgical case of this type in athletes, seen at this office during the period 1938–1948, has been omitted from this report. No attempt has been made to report non-surgical cases

which were in the majority, especially in the early years; in many of these, reconstruction was later necessary. The sharp increase in patients operated upon in 1946, 1947, and 1948 continued in 1949, with fewer non-surgical cases. The indication for surgery becomes more definite with increasing experience.

CONCLUSION

Major improvement in the management of injuries to athletes can be assured by early diagnosis and prompt definitive treatment. Nowhere is this better illustrated than in the surgical management of serious injury to the medial collateral ligament, anterior cruciate ligament, and medial meniscus of the knee.

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DISCUSSION

Dr. David M. Bosworth, New York, N. Y.: This paper is productive of much thought. The impressions arising in connection with it are elusive. The theoretical advantage of early repair may be outweighed by mistakes in preoperative diagnosis and other factors. While Dr. O'Donoghue said one should find and repair each tear, unfortunately, in badly injured knee structures, the lacerations are not clean-cut transections, but are fibrillated; and the ligamentous structures are frequently destroyed. The injuries found may be irreparable, and in such a case the added insult of exploration will not be beneficial. Whether a severely damaged knee is repaired or not, I do not believe that the patient should be encouraged to return to top-flight athletic activities. Such a repaired knee joint, while it might wear for ordinary usage of life, may not stay stable under severe strain. Some knees may need immediate care, but I personally would delay repair at least for recession of the influences of the acute trauma.

DR. T. B. QUIGLEY, BOSTON, MASSACHUSETTS: I wish to congratulate Dr. O'Donoghue on his excellent presentation.

There is no question that prompt, precise surgical restoration of continuity of avulsed collateral ligaments at the knee is the treatment of choice. During a recent fifteen-month period, we had an opportunity at the Peter Bent Brigham Hospital in Boston to study six such cases [1]. In two of these, the force involved was so severe as to produce dislocation. One of these dislocations was the only case of the series treated conservatively, and the result was the worst in the series. Reduction was carried out forty minutes after injury. The knee is now satisfactory, but flexion beyond 100 degrees has been lost. In retrospect, we regard this experience as fortunate in view of the findings in the other dislocation.

The dislocation in the second case occurred in a football player who was blocked by another player. A complete lateral dislocation occurred which was reduced immediately on the playing field. Four days later, the joint was exposed from the medial aspect at operation. The distal end of the medial collateral ligament lay transversely across the joint, the medial meniscus was in the intercondylar notch, and the anterior cruciate ligament was avulsed in its mid-portion. A suture was placed in the anterior cruciate ligament.

The patient was able to walk on the football field without assistance five weeks later, and he was able to participate in college baseball four months after injury.

We do not agree with Dr. O'Donoghue that the repair of the cruciate ligaments is necessary. We have at times sutured, and at other times excised, torn cruciate ligaments,—not with any idea of restoring strength, but rather to get the dangling ends out of the way and to eliminate a possible cause of subsequent internal derangement. In this regard, we are in complete agreement with the late Dr. Darrach of the Presbyterian Hospital, New York City. The knee can be considered as a physiological unit; loss of one of its many components is not serious; and, if this component is the anterior cruciate ligament, it can even be insignificant provided the muscles of the knee are good.

There is a considerable group of these cases in which it is difficult to decide whether surgical exploration is necessary. One of our criteria has been late instability of 15 degrees or more, when compared with the opposite uninjured knee. This point has been well established by experimental work.

Aspiration under anaesthesia, manipulation with roentgenographic examination, and operation, if marked instability is discovered, have been recommended for all injured knees which present marked effusion immediately after injury. In none of our cases was effusion a notable factor. Most of them instead presented a doughy, diffuse, subcutaneous oedema of the whole anterior aspect of the joint. This was felt to be caused by leakage of blood and joint fluid through rents in the capsule, which were demonstrated at operation in every case.

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DR. O'DONOGHUE (closing): I appreciate very much the gentlemen's discussion of this problem. Of course, we all have a great respect for Dr. Bosworth's opinion, particularly in regard to conditions about the knee.

I must say that in the course of the ten years covered by this report, we have operated upon some twenty patients. This is not a large number when you consider the great many knees that are ordinarily seen in the course of a year. I think this group of athletes is a unique group. They are eighteen to twenty years of age, and at the prime of life; they are in wonderful physical condition, or they would not be athletes. I think our goal here should be complete, 100 per cent. recovery. I think we should not willingly consign these patients to a life of relative inactivity. I do not mean to imply that Dr. Bosworth suggests that either, but I want to emphasize that too many times we are inclined to temporize with these cases. The result is that the time for favorable operative results has passed, and we are faced then with a reconstruction, rather than a repair, which is an altogether different problem.

Dr. Quigley has had some very interesting cases. These were cases of complete dislocation of the knee, very drastic injuries, and present a very serious problem. The reason I am particularly interested in the cruciate ligament and for this reason must disagree with Dr. Quigley regarding the necessity for its repair is that I repeatedly see patients whose only disability is relaxation of the cruciate ligament. I think this can be prevented. If diagnosed accurately at the time of injury, repair is relatively easy, and prognosis is good. After healing has taken place, repair is not only much more difficult, but is much less satisfactory. For this reason, I believe that even an isolated injury of the cruciate ligament should be repaired early.

EXPERIMENTAL AND CLINICAL USE OF OXIDIZED CELLULOSE AND CORTISONE IN THE PREVENTION OF EXCESS BONE AND FIBROUS-TISSUE FORMATION*

BY FRANK E. STINCHFIELD, M.D., NEW YORK, N. Y.

From New York Orthopaedic Hospital, Columbia-Presbyterian Medical Center, New York City

Although the technical and mechanical aspects of reconstructive joint surgery have been mastered to a relatively high degree, improved orthopaedic procedures are needed to obtain more motion. On the thesis that for further improvement we must look to the fields of physiology and chemistry, research was instituted by the author in 1945.

One of the chief factors interfering with a satisfactory end result in joint surgery is the limitation of motion postoperatively, due to excess bone and fibrous-tissue formation at or near the site of surgery. A method was sought which would limit bleeding at the arthroplasty site and decrease the amount of bone production. It was considered that the material described by Frantz, Clarke, and Lattes—namely, oxidized cellulose (absorbable gauze)—might reduce the excess bone formation.

Lattes and Frantz stated, in November 1945, that this material is cellulose which has been oxidized by the use of nitrogen dioxide. It becomes anhydroglucuronic acid, which, when inserted into the tissues, produces a lowered pH. Oxidized cellulose is soluble in dilute alkali. The material used is sterilized by formaldehyde. Several interesting facts were revealed by dog experimentation.[3] In one instance the oxidized cellulose was placed between the fragments of a fractured radius, and the fracture failed to unite. The cavity "was lined by flattened cells, making it resemble an adventitious bursa. Also here, there were minimal, if any, microscopic signs of bone repair." In experimental work with dogs it was proved that, when oxidized cellulose was interposed between the fracture fragments, complete non-union developed. Photomicrographs ninety-one days after experimental fracture showed complete lack of osteoid callus. In one experiment, when the seventh, eighth, and ninth ribs of a dog were fractured, oxidized cellulose was placed between the fracture ends of the ninth rib, while fibrin foam was placed between the ends of the seventh rib. The eighth rib was used for control. Autopsy, performed forty-two days after fracture, showed absolutely no new-bone formation between the fracture ends of the ninth rib, in which the oxidized cellulose had been introduced, whereas moderate new bone appeared between the ends of the seventh rib, where fibrin foam had been used. There was almost solid bony union of the eighth rib.

To test the clinical application of oxidized cellulose gauze, the author has used it in twenty-two joint arthroplasties and in twenty cases where the prime purpose was to limit recurrence of bone production, as in removal of exostoses, in myositis ossificans, and in resection of radial heads. In general, the oxidized gauze is inserted wherever a recurrence of bone might compromise a satisfactory result. "Gelfoam" is used as packing where hemostasis, but not inhibition of bone production, is desired, as in bone cavities or after removal of bone from the wing of the ilium to be used in spine fusions. Gelfoam gives the desired hemostatic effect and will act to fill dead space, but does not inhibit bone formation as does oxidized cellulose gauze.

In the arthroplasty series, arthroplasty was performed in each instance by the ordinary technique and then oxidized cellulose was introduced into the joint itself to prevent bleeding and to limit bone production. This series consists of nine of the Smith-Petersen

* Read at the Annual Meeting of The American Orthopaedic Association, Virginia Beach, Virginia, May 25, 1950.

type of mold arthroplasty of the hip; four arthroplastic débridements of the knee joint, as advocated by Magnuson; two arthroplasties of the knee joint, where only oxidized cellulose was used to cover the raw bone surfaces of the newly reshaped femur and tibia; two arthroplasties of the elbow; and five Keller procedures for hallux rigidus. The longest follow-up has been four and one-half years.

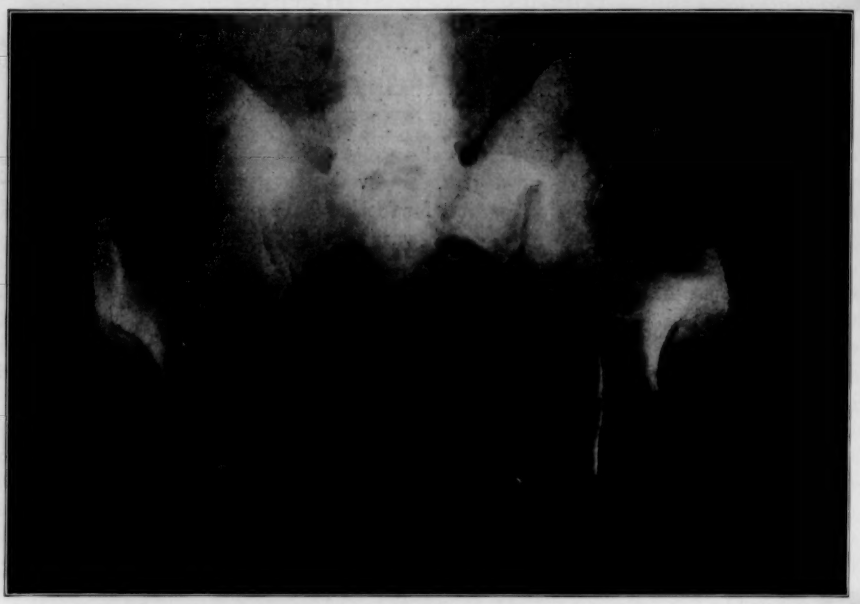

FIG. 1-A

Patient having bilateral subluxation of hip. It was necessary to perform an arthroplasty on the right.

FIG. 1-B

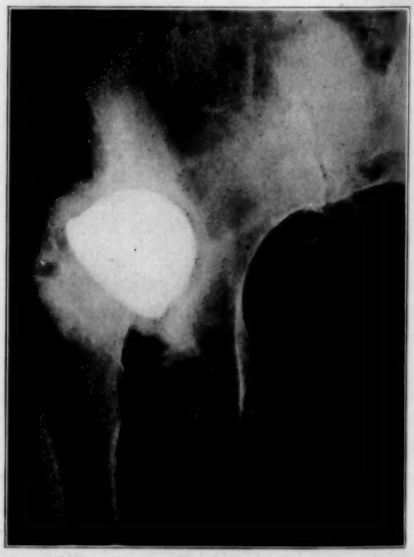

FIG. 1-C

Fig. 1-B: Roentgenogram taken immediately after arthroplasty.
Fig. 1-C: Bony encapsulation of Vitallium mold, seven months after operation.

In this series the patients seemed to be comfortable after operation and the degree of motion was greater than that achieved without the use of oxidized cellulose. The gauze in the immediate proximity of the bleeding bone apparently interferes with the normal process of bone production by the following means:

1. The gauze acts as a hemostatic and can be left in place for a long period, thus preventing a large hematoma at the arthroplasty site. There seems to be no harmful effect on the tissue, other than a decrease of new-bone proliferation.

2. As Lattes and Frantz stated, the oxidized cellulose is "slightly acid and it probably retains its acid reaction even after having been partly broken down and phagocytized. This is suggested by the fact that the cytoplasm of the characteristic phagocytes, which are present in tissues following introduction of oxidized cellulose, is always more or less basophilic. . . . In these bone experiments, some phagocytes were still to be seen in the specimens of animals sacrificed 56 days after operation. . . . It becomes natural, therefore, to think that the interference with bone healing might depend on a low local pH. This would

FIG. 1-D

Roentgenogram taken immediately after revision of arthroplasty of hip.

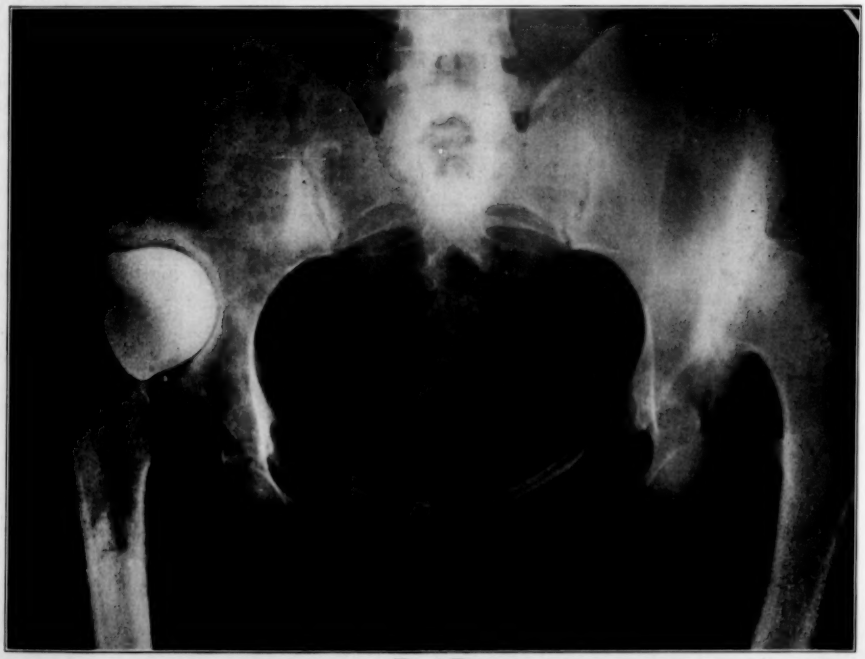

FIG. 1-E

Result after the use of oxidized cellulose.

FIG. 2-A

FIG. 2-B

Figs. 2-A and 2-B: Anteroposterior and lateral roentgenograms before operation.

almost certainly damage already formed bone and interfere with the concentration of inorganic calcium salts, which is a prerequisite for the formation of new bone."

3. There is also the possibility that the oxidized cellulose interferes with the activity of the enzyme phosphatase.

Figure 1-A is the roentgenogram of a patient who had bilateral subluxation of the hip in which, because of increasing pain and limitation of motion, an arthroplasty of the right hip was necessary. Figure 1-B shows the result immediately following a Smith-Petersen cup arthroplasty. The patient gradually lost motion in the hip operated upon until, seven months after operation, there was absolutely no motion because of bony encapsulation of the mold (Fig. 1-C). A revision of the arthroplasty was performed (Fig. 1-D). This time three grams of oxidized cellulose was introduced into the arthroplasty site. The motion increased after operation, and at the end of one year the patient had 65 degrees of flexion, 25 degrees of abduction, 10 degrees of internal rotation, and 5 degrees of external rotation.

Figures 2-A and 2-B are the preoperative roentgenograms of a patient requiring arthroplasty because of arthritis secondary to an old slipped upper femoral epiphysis. Figures 2-C and 2-D show the right hip eighteen months after operation. Oxidized cellulose

FIG. 2-C

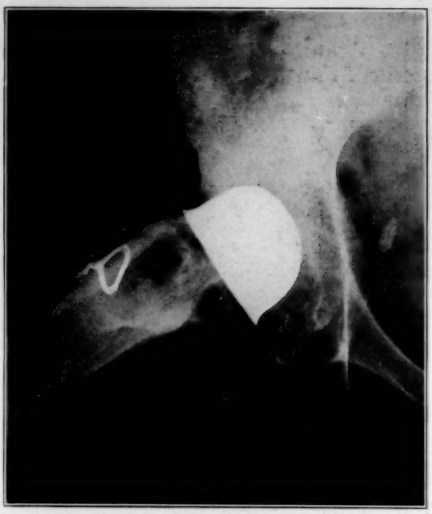

FIG. 2-D

Anteroposterior and lateral roentgenograms, eighteen months after arthroplasty. Oxidized gauze was used initially. Note the relatively small recurrence of new-bone production.

was used initially and the patient regained almost normal motion without excess bone being produced.

Photomicrographs are shown of a specimen taken from a hip joint following an arthroplasty in which oxidized cellulose was used (Figs. 3-A and 3-B). An elongated mass of tissue contains irregularly arranged areas of hyaline cartilage with basophilic matrix along one side, making transition to bone at the edge. Elsewhere, and for the most part, the section shows pale-staining, partly degenerated hyaline cartilage and fibrocartilage. The matrix stains very poorly. Such cartilage forms the irregular natural border of the section, except where it is additionally covered by old fibrin.

Although bone formation could be inhibited by the use of oxidized cellulose, fibrous-tissue formation progressed normally or at an accelerated rate. Therefore, it was necessary to attempt some means of retarding the growth of fibrous tissue in order to overcome another major complication in traumatized joints and in joint arthroplasties.

Experimental work by Ragan, Howes, and their associates has shown that wound healing is markedly inhibited by the administration of cortisone. The mechanism whereby cortisone suppresses growth of connective tissue following trauma is not entirely clear. However, it would seem that the catabolic effect of hyperadrenalism on protein metabolism may account for the decreased activity of mesenchymal tissues.

When trauma of any part occurs, there is a concurrent chemical change. One hypothesis is that the trauma causes an enzyme reaction. Cortisone interferes with this reaction, with the consequence that enzymes cannot stimulate fibrous-tissue formation. Thus, not much ground substance is produced. When cortisone is administered, there is no fraying or swelling of the collagen fibers. The cortisone hinders degeneration of collagen and thus prevents fibroplastic proliferation.

To determine the various effects of cortisone on the end results of arthroplasties, four types of dog experiments were performed. Three dogs were used in each experiment, or a total of twelve hips.

First, as a control, no cortisone was used. In this series an arthroplasty was performed and a nylon mold was applied over the head of the femur.

Second, the same type of arthroplasty was performed, but 25 milligrams of cortisone

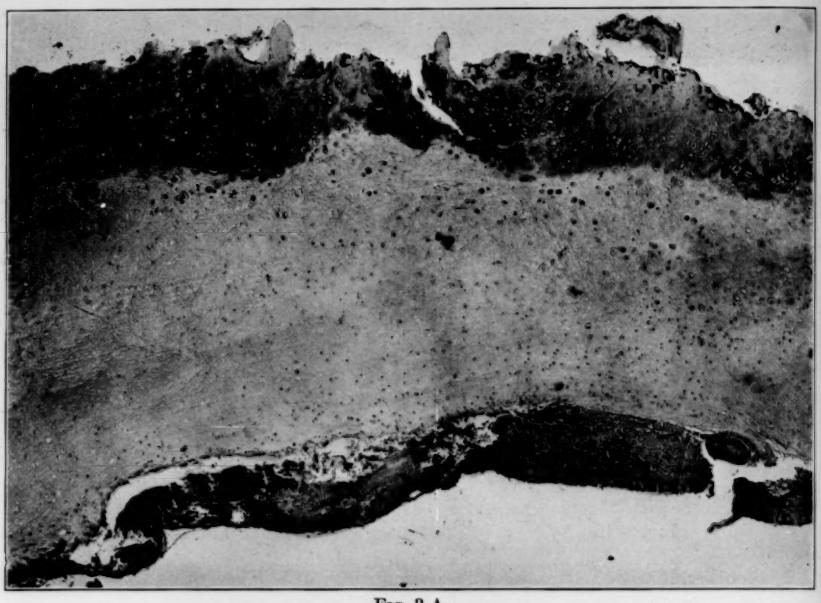

FIG. 3-A

Low-power photomicrograph of specimen of acetabular cartilage, three years after introduction of oxidized cellulose into the hip joint. Note the narrow, elongated mass of tissue, and irregularly arranged areas of hyaline cartilage with basophilic matrix along one side, making transition to bone at the edge.

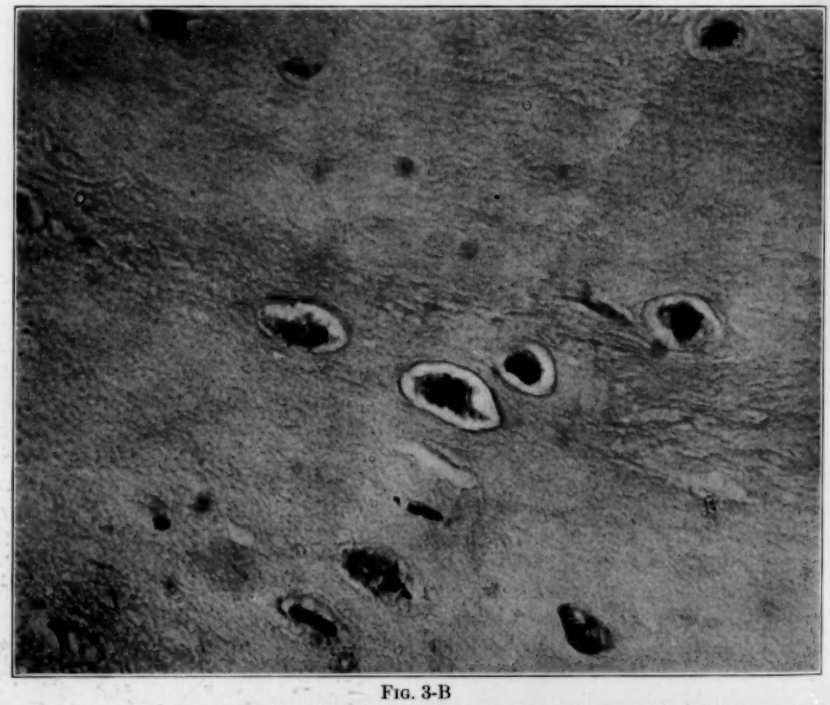

FIG. 3-B

High-power photomicrograph of the same specimen, showing fibrocartilage and pale-staining matrix.

FIG. 4

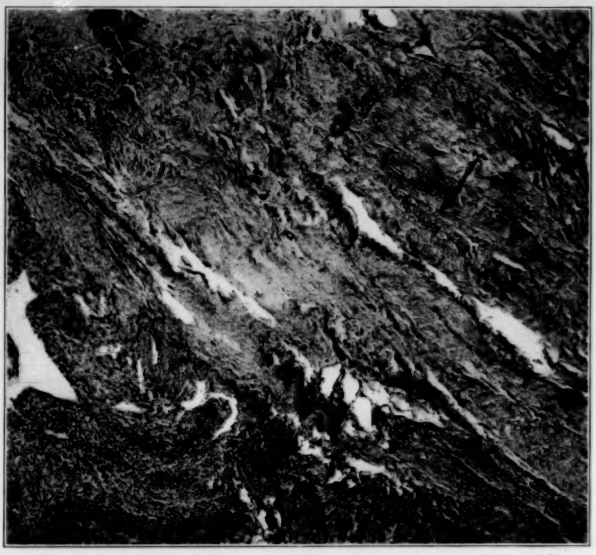

FIG. 5

Fig. 4: Roentgenogram of hip of dog in control series.
Fig. 5: Microscopic section of capsule of a dog in control series. Note marked fibrous-tissue formation.
Fig. 6: R. 249. Roentgenogram of hip joint in dog of series treated only by local injection of cortisone directly into hip joint.

was instilled into the joint at the time of operation. Two days later the hip joint was again injected with 25 milligrams of cortisone; this procedure was repeated at the end of four days, for a total of three local instillations of cortisone.

Third, 25 milligrams of cortisone was instilled locally at the time arthroplasty was performed. Following operation, daily for three weeks, 10 milligrams per kilogram of body weight was injected intramuscularly.

In the fourth type of experiment, the dogs were given intramuscular cortisone, 10 milligrams per kilogram, for two successive days before the operation and the same amount on the day of operation, but none locally at the time of arthroplasty. For three weeks after operation, they were given 10 milligrams per kilogram intramuscularly each day.

An arthroplasty was performed on the right hip in each instance. To facilitate exposure, it was necessary at the time of surgery to osteotomize the greater trochanter in each of the dogs. The acetabulum was well reamed out and a nylon cup was placed over the denuded femoral head. The capsule was closed in each instance. No splinting or immobilization was used after operation. In all except the control series, the animal was bearing weight on the limb within four days; the control animals were bearing weight at six or seven days. All of the animals were sacrificed five weeks

FIG. 6

FIG. 8

Microscopic section of capsule of hip joint in dog treated by local injection of cortisone. Note slight to minimal fibrous-tissue proliferation at margin.

FIG. 7

Photomicrograph shows healing of skin incision, where local cortisone had been injected into hip joint.

after the arthroplasty had been performed.

At the time of autopsy, the findings were recorded as follows:

Control Group

The gross hip specimens showed a great deal of crepitation. (This was the only series in which crepitation was observed.) Excess fluid was noted and the capsule was markedly thickened. There was no degenerated fibrin or connective tissue within the joint, as observed in the animals treated with cortisone. Motion of the joint was compromised because of the abnormally thickened capsule. Although it is impossible to evaluate accurately the amount of motion, it was the author's opinion that the control dogs had about one third less motion than the dogs given cortisone.

A roentgenogram of the autopsy specimen of a control dog is seen in Figure 4. Figure 5 shows a microscopic section of the capsule of a control dog. There are few capillaries and marked proliferation of fibrous tissue.

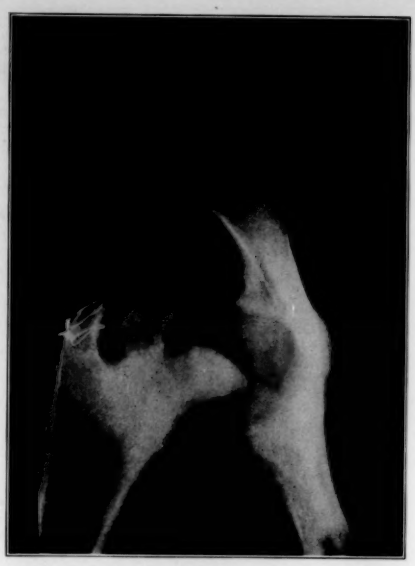

FIG. 9

R. 271. Roentgenogram of hip joint of dog. Cortisone was injected locally at time of surgery and systemically thereafter.

Group 2

Cortisone was injected locally into the joint on three occasions. At autopsy the joint showed good motion, no crepitation, and no evidence of periarticular swelling (Fig. 6). There was clear fluid in the joint and a considerable amount of white degenerated fibrin. The capsule was slightly thicker than in the dogs given one instillation of cortisone at the time of surgery with daily injections postoperatively.

A microscopic section of the skin incision in a dog of this series (Fig. 7) shows definite evidence of skin healing, even though cortisone had been used locally. In a microscopic section of the capsule (Fig. 8), there is slight, if any, marginal proliferation of fibrous tissue, no inflammatory reaction, and no new formation of capillaries.

Group 3

Cortisone was given locally at the time of operation and systemically daily thereafter for three weeks. Autopsies of animals in this series showed the best results (Fig. 9). The motion was excellent and normal as compared to the hip not operated upon, and the cup moved freely, both on the head and in the acetabulum. There was no evidence of inflammation or of fibrous-tissue formation. Again, considerable degenerated fibrin and connective tissue were found in the joint.

In a microscopic section of this type of capsule (Fig. 10), there is no fibrous-tissue proliferation; the joint margin is smooth and is composed of dense fibrous connective tissue, which had been present before surgery. In these microscopic sections, the capsule is thin. None of these sections shows any chronic inflammation.

Group 4

Cortisone, 10 milligrams per kilogram, was given intramuscularly for two days before operation, on the day of operation, and postoperatively for twenty-one days. Again in this series, no crepitation could be detected at the time of autopsy. A great deal of degen-

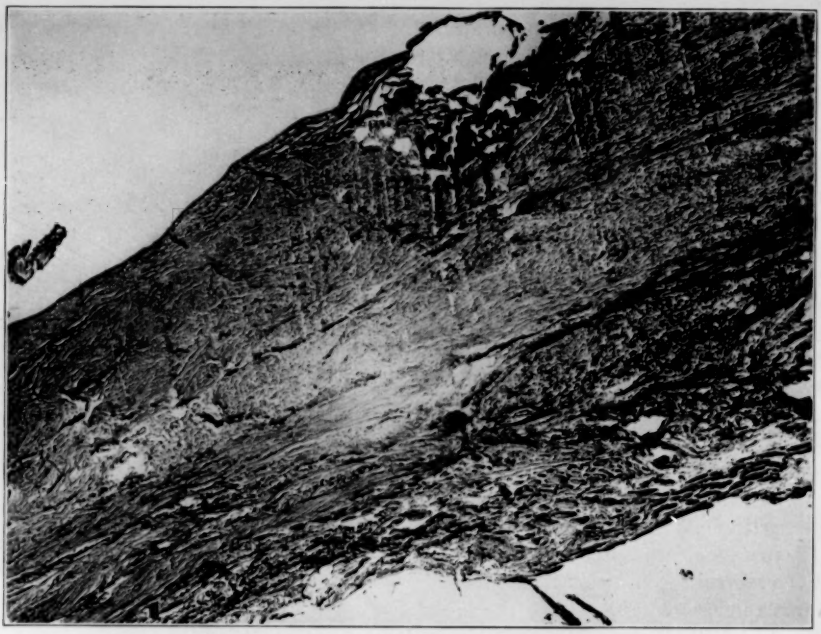

FIG. 10

Microscopic section of capsule of dog. Cortisone was first injected locally, and then given systemically for three weeks. Note the absence of all fibrous-tissue proliferation and inflammatory reaction.

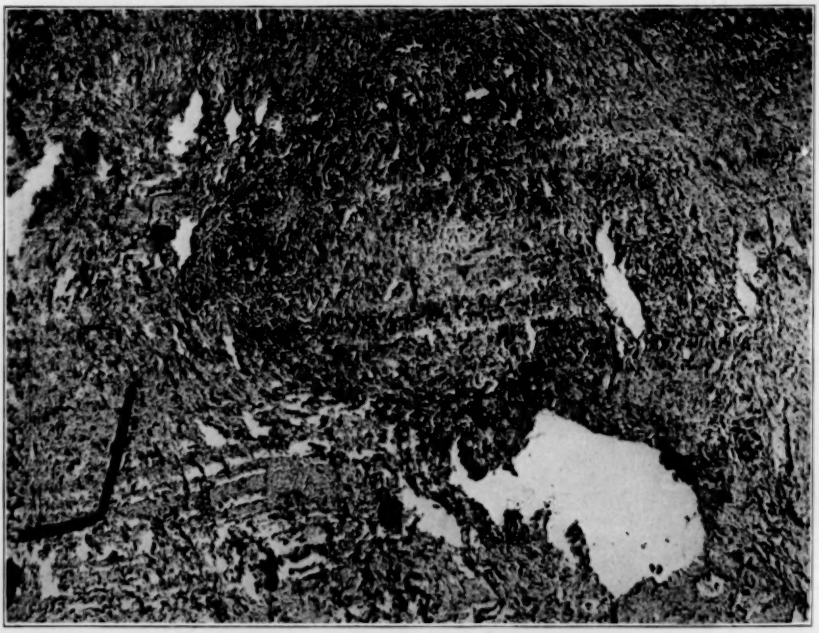

FIG. 11

Microscopic section of capsule of dog to which only systemic cortisone was given. Amount of fibrous tissue is increased as compared to Fig. 10, but markedly less than in Fig. 5.

erated fibrin was found. The capsule as a rule measured about one third the thickness of that of the control series. There was universally more motion than in the control group. In a microscopic section of the capsule (Fig. 11), there is a moderate amount of fibrous-tissue proliferation with collagen formation. Blood capillaries are present, as well as newly formed connective tissue (Chart I).

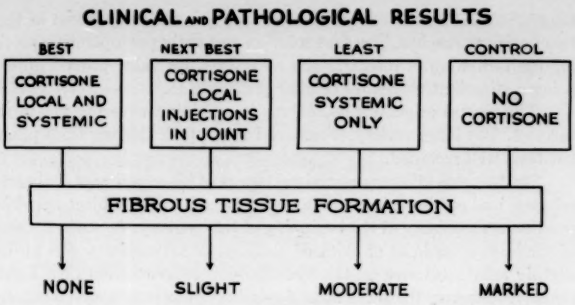

CHART I

The best results were obtained when cortisone was both injected locally into the joint and given systemically thereafter.

In the cortisone-treated animals, as compared to the controls, there were:

1. Less thickening of the capsule;
2. More free motion;
3. Less crepitation;
4. No inflammatory reaction.

From these experiments it would seem that cortisone has much to recommend it where inhibition of fibrous-tissue formation is desired. The chief value of cortisone is its direct effect locally at the site of surgery, where theoretically it retards the enzyme, or allergic manifestation, producing fibrous and connective-tissue formation. It would also seem that local injection of cortisone, together with systemic intramuscular administration, offers the greatest help in preventing fibrous-tissue formation.

With these facts in mind, clinical application has been initiated. Humans are much more sensitive to cortisone than dogs, and the systemic administration inhibits wound healing. Therefore, our policy in treating traumatized joints or in performing arthroplasties is as follows: 100 milligrams of cortisone is injected into the joint at the time of operation and the dose is repeated on the second, fifth, tenth, and fifteenth days after operation. On the seventh postoperative day, when sufficient time has elapsed for the skin wound to be well healed, 100 milligrams of cortisone is given intramuscularly, and this amount is repeated daily for three weeks.

Sufficient time has not elapsed to evaluate the results in humans. However, the results of our experiments so far are encouraging, and they may contribute toward lowering the percentage of complications relative to fibrous tissue and bone formation following operative orthopaedic procedures.

NOTE: Funds for this research were provided by the United States Public Health Service and by Merck and Company, Inc.

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DISCUSSION

DR. EDGAR M. BICK, NEW YORK, N. Y.: The control of excessive postoperative osteogenesis and fibrosis is probably one of the most difficult hurdles in joint surgery. During the past fifty years or so, many

suggestions have been offered to overcome this difficulty. Most of them, however, are modifications of just two basic approaches. The first solution was early postoperative motion, based on the principle of preventing the formation of interarticular adhesions. Its value proved quite limited and it even was suspected of being a stimulant to greater cellular proliferation.

The second original solution was to employ a covering membrane or cap over the newly formed joint surfaces. The large variety of material so applied, ranging from pliable pig bladder to rigid Vitallium cup, has been well recorded.

Dr. Stinchfield's very restrained report of his experimental observations and clinical trials with oxidized cellulose and cortisone is the first new approach to the subject that I know of since the introduction of interposition arthroplasty at the beginning of this century. As such, it deserves careful consideration. Adaptation of the known qualities of oxidized cellulose to arthroplasty was an ingenious concept. The influence of the slightly acid substance on the hydrogen-ion concentration of a local area is in itself a valid explanation. Grossly, however, the mere fact of relative hemostasis may be sufficient to restrain bone production, since the formation of granulation tissues in fresh blood in the neighborhood of traumatized bone is the first step in retarding osteogenesis.

The use of cortisone brings quite another problem. An attempt to control regional fibrosis by local and systemic use of cortisone draws into discussion the entire field of adrenal cortical physiology. This field has been entered only recently, and it is not yet entirely explored. I have gone through all the available current literature on cortisone and adrenal physiology at the New York Academy of Medicine, hoping to find reports of experimental work that might reinforce Dr. Stinchfield's observation. Except for the work of Ragan and his associates, to which Dr. Stinchfield has alluded in his paper, I could find nothing in reference to the local effect which might be compared to this very highly original approach. However, one cannot help wondering why cortisone should be so selective in its effect after arthroplasty and why it should not retard the growth of connective tissue where it is needed as well as where it would be disadvantageous.

The originality of Dr. Stinchfield's concept and the very great importance of the objective is such as to make it almost a moral obligation that this work be continued. If its clinical success can be further demonstrated, theoretical explanations will follow in due course. Dr. Stinchfield is to be complimented most enthusiastically for opening another original approach to a problem heretofore inadequately understood.

Dr. J. Albert Key, St. Louis, Missouri: A paper as interesting and original as this should not be passed over without discussion.

I notice that the bone was healed in all of these cases where the trochanter was removed. On the other hand, in the subcutaneous tissue the scar was occupied largely by a cystic cavity. When cortisone gets so cheap that we can afford to use it, I would expect a good many more postoperative complications than we now have, because apparently the drug may delay wound healing as well as lessen the production of new bone. In doing arthroplasties it has been my practice to excise the capsule; however, Gibson[1] didn't touch the acetabulum in his cases and he carefully sutured the capsule, and yet his results looked better than mine.

As Dr. Bick says, it is going to be very difficult to learn to control the action of cortisone. We shall have to so balance our dose that wounds will heal and at the same time not heal too much. I can see the possibility of a field for this in tendon surgery, provided we can get the tendon to unite.

I have been treating some of these old arthritic hips by excising the capsule completely plus a cheilotomy, but without doing an arthroplasty,—a modified form of neurectomy. The patients have done very well and the convalescence is smooth and short.

The use of oxidized cellulose for inhibiting callus is very ingenious. I have used oxidized cellulose for packing bone defects and in clean wounds; the bone promptly healed and the oxidized cellulose apparently disappeared.

1. Gibson, Alexander: Vitallium-Cup Arthroplasty of the Hip Joint. Review of Approximately One Hundred Cases. J. Bone and Joint Surg., **31-A:** 861–868, Oct. 1949.

Dr. W. McDaniel Ewing, Louisville, Kentucky: I used oxidized cellulose in one case of malignant chondromyxosarcoma at the upper end of the tibia, where there was a very large bone defect. I was planning on it promoting hemostasis, rather than the result that Dr. Stinchfield has pointed out. The patient was a man in his fifties who had had this tumor since 1933. He had received radiation therapy in 1935. The defect was three to three and one-half inches at the upper end of the tibia, and all the tumor tissue had been cleaned out. Oxidized cellulose was placed in the defect and, after a period of three weeks, there was complete repression of fibrous-tissue formation. The wound failed to heal and amputation was required later.

Dr. Stinchfield (closing): I want to thank Dr. Bick, Dr. Key, and Dr. Ewing for their discussions. Dr. Bick was extremely kind,—much more so than he should have been because I am sure that, although we decided to do something a little different, we do not as yet know all of the complications and have much more to learn.

(*Continued on page 766*)

CHANGES IN THE SCOLIOTIC SPINE AFTER FUSION

BY IGNACIO V. PONSETI, M.D., AND BARRY FRIEDMAN, M.D., IOWA CITY, IOWA

From the Department of Orthopaedic Surgery, State University of Iowa, Iowa City

The roentgenograms of 117 cases of scoliosis, treated by fusion of the spine, were studied to determine the changes which occur in the vertebral bodies, in the intervertebral spaces, and in the fused and non-fused segments of the spine.

Conservative measures to control severe idiopathic, paralytic, and congenital curvatures of the spine may fail. Spine fusion is a palliative operation to which the orthopaedic surgeon is forced to resort in some cases. In the cases studied, spine-fusion operation was performed for either of two reasons: (1) in young patients, in an attempt to stop the progression of scoliosis; (2) in patients after maturity of the skeleton, in order to maintain the correction obtained by traction, wedging, or turnbuckle casts.

MATERIAL

One hundred and seventeen cases of scoliosis treated by spine fusion were analyzed after a minimal follow-up period of three years and an average follow-up of eight years. All of the cases were treated in the Department of Orthopaedic Surgery of the State University of Iowa Hospitals. There were fifty-one cases of idiopathic scoliosis, forty-three cases of paralytic scoliosis, and twenty-three cases of congenital scoliosis. The ages of the patients at the time of spine fusion varied from four to twenty-eight years; seventy-six patients were under fourteen years of age. The average age at the time of fusion was twelve years and one month.

Preoperative correction of the spinal curvature was attempted in 100 cases. Correction of 20 degrees or more was attained in all but nineteen. A Risser jacket was used in seventy-one cases, and traction and a plaster bed in twenty-nine cases. No preoperative correction was attempted in seventeen cases.

The technique of fusion usually employed was that described by Steindler, which is a combination of the Albee and Hibbs methods. Tibial and iliac grafts were used to reinforce the Hibbs fusion. In sixty-five cases, the grafting operation was performed only on the concave side of the curvature; in fourteen, it was performed on both sides. In thirty-eight cases, the Hibbs technique was used on both sides of the vertebrae. The average number of vertebrae fused per patient was ten. Only four vertebrae were fused in one case; in six cases, seventeen vertebrae were fused. Extensive fusions were usually performed in two or three stages. The patients were immobilized in the recumbent position for an average of five months after the spine fusion. A body brace was then applied for an average of fourteen months.

METHOD OF STUDY

Anteroposterior and lateral roentgenograms of the spine, taken every three to six months with the patient in the standing and supine positions, were available for study. All were taken with a focal film distance of thirty-six inches. In each film, measurement was made of the length of the segment from the center of the body of the upper fused vertebra to the center of the body of the lower fused vertebra, as well as the length of the non-fused segments proximal and distal to the fused area. The width and height of several of the vertebral bodies and the height of the best visualized intervertebral spaces in the fused and non-fused segments were also measured. Roentgenograms were often obtained with the patient in bending positions, in order to determine the presence of pseudarthrosis or the stability of the curves. The angles of all of the curves present were measured ac-

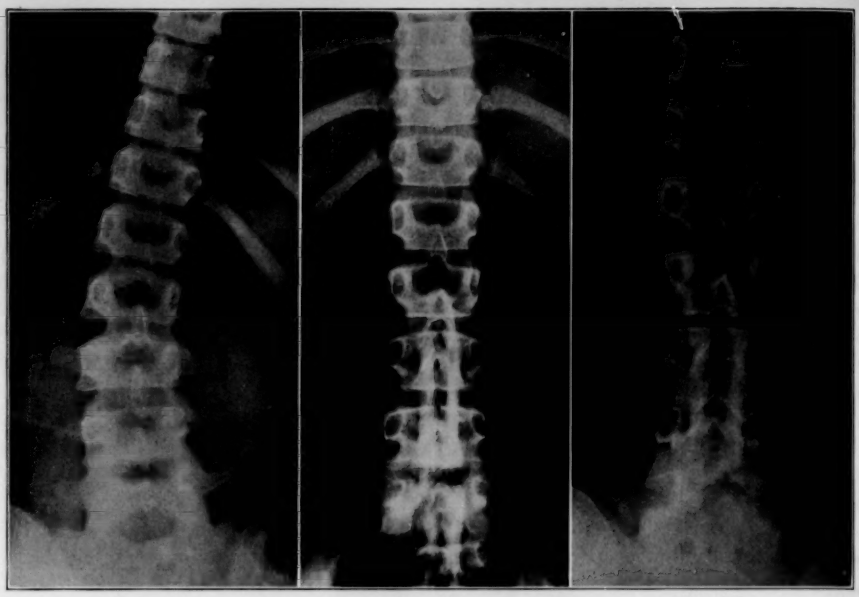

FIG. 1-A FIG. 1-B FIG. 1-C

Fig. 1-A: Roentgenogram of a seven-year-old girl who had had acute anterior poliomyelitis at the age of six years, with initial paralysis of abdominal muscles and right lower extremity. Spine was fused from second lumbar vertebra to sacrum.

Fig. 1-B: One year after operation, showing pseudarthrosis between fourth and fifth lumbar vertebrae.

Fig. 1-C: Four years after spine fusion, pseudarthrosis persisted. The fused segment had not grown appreciably in length. Fused vertebrae had grown in height and disc spaces had narrowed. Second lumbar vertebra appeared trapeziform.

cording to the method previously described by the authors [1]. Clinical examinations were conducted before fusion and at each subsequent visit. The clinical evaluation was often not made personally by the authors, but data were obtained from the clinical records and from photographs of the patients.

RESULTS

Growth of the Fused Segment of the Spine after Operation

Of the patients who were under fourteen years of age at the time of spine fusion, sixty-two had a postoperative follow-up averaging six years and six months. The growth of the fused segment was determined in these cases. In thirty-two cases (52 per cent.), the fused segment did not grow at all after operation. In thirty cases (48 per cent.), there was slight growth of the fused segment, varying from 0.1 to 3 centimeters; the average growth was 1.23 centimeters. In fourteen (47 per cent.) of these cases, the growth was less than 1 centimeter.

There seemed to be no correlation between the method of spine fusion and the growth of the fused segment, nor between the age of the patient at the time of fusion and the growth of the fused segment. Of the thirty cases in which the fused spinal segment grew, twenty-five (83 per cent.) had pseudarthrosis of the grafted area. In none of the remaining five cases in which pseudarthrosis did not develop, did the fused segment grow more than 1 centimeter.

The growth of the fused segment, then, was nil or minimal except in the cases in which pseudarthrosis developed. However, each individual vertebral body of the fused segment grew somewhat in height and in width. Conversely, the intervertebral space became very narrow, although usually it did not disappear completely (Figs. 1-A, 1-B, and 1-C). The

increase in height of the vertebrae varied according to the age of the patient at the time the fusion was done. The younger the patient, the greater the growth in height of the vertebrae and the narrower the intervertebral spaces. The average growth in height of each vertebra in the fused segment was 0.44 centimeter. The average preoperative width of the intervertebral space was 0.48 centimeter; at the end of the period of observation the average width was 0.24 centimeter, or an average decrease of 0.24 centimeter.

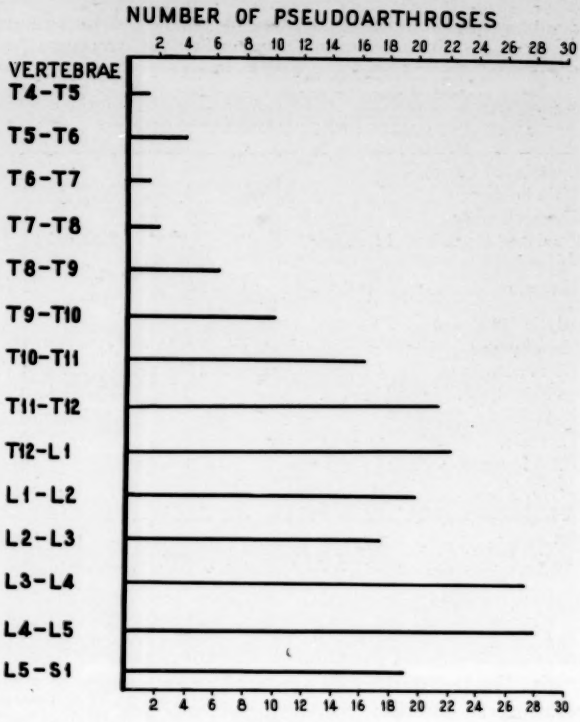

CHART I

Site and frequency of pseudarthroses.

Although the growth in height of a vertebra within the fused segment might be expected to correspond to the decrease in width of its adjacent intervertebral spaces, there was a discrepancy of 0.2 centimeter. This difference may be due to the fact that the vertebrae and the intervertebral spaces measured were, in some instances, in different regions of the fused segment. Of course, in each case the measurements were made of the same vertebrae and intervertebral spaces throughout.

The vertebral bodies of the fused segment did not grow in width as much as did the vertebral bodies of the non-fused segment. The vertebrae at the ends of the fused segment sometimes appeared trapeziform. The half of the vertebra on the side of the fusion did not grow as much as did the half which articulated with the non-fused segment of the spine (Fig. 1-C). The portion of the vertebral body on the convex side of the curve grew more in height than did the portion on the concave side. On the convex side, the vertebral body was osteoporotic; on the concave side it was sclerotic.

Pseudarthrosis

Pseudarthrosis of the grafted area was seen on the roentgenograms in eighty cases (68.3 per cent.), most frequently below the level of the tenth thoracic vertebra (Chart I). Of the eighty cases in which the lumbar spine was fused below the level of the second lumbar vertebra, pseudarthroses were detected in sixty-six (83 per cent.). They were most common at the following sites: between the fourth and fifth lumbar vertebrae (twenty-eight cases), between the third and fourth lumbar vertebrae (twenty-seven cases), and between the twelfth thoracic and first lumbar segments (twenty-two cases). Multiple pseudarthroses were often observed in extensive fusions. On the other hand, pseudarthrosis was rarely seen in short fusions of the thoracic spine. The development of pseudarthrosis was, then, related to the mobility of the spinal segment and to the extent of the fusion.

The type of spine fusion did not seem to influence the development of pseudarthrosis.

TABLE I

FINAL ANGULAR VALUES OF SPINAL CURVATURES TREATED BY FUSION

Etiology and Pattern of Scoliosis	No. of Cases		Under 40 Degrees	From 40 to 60 Degrees	From 60 to 80 Degrees	Over 80 Degrees
Idiopathic (51 Cases)						
Main lumbar	5		2	0	2	1
Thoracolumbar	10		1	3	3	3
Combined thoracic and lumbar	12	Thoracic	0	3	6	3
		Lumbar	2	2	5	3
Thoracic	24		1	4	3	16
Paralytic (43 Cases)						
Main lumbar	7		1	1	3	2
Thoracolumbar	17		4	3	3	7
Combined thoracic and lumbar	4	Thoracic	0	2	2	0
		Lumbar	0	2	2	0
Thoracic	13		0	2	4	7
Total C curve	2		0	0	1	1
Congenital (23 Cases)	23		6	5	5	7
Total	117		15	23	32	47

However, pseudarthroses were not so frequent in cases in which a massive amount of bone had been used for the grafting procedure. Prolonging the duration of postoperative immobilization beyond five months did not appear to diminish the occurrence of pseudarthrosis. The pseudarthroses appeared at an average of eleven and one-half months after operation. In one case, pseudarthrosis was first detected five years after surgical fusion of the spine.

Of fifty-two cases of pseudarthrosis, followed for a period of six years, spontaneous closure was seen in nineteen. Spontaneous closure took place when the scoliosis became

TABLE II

RESULTS OF FUSION IN SCOLIOSIS

Etiology and Pattern of Scoliosis	Patients 10 Years or Less at Time of Fusion			Patients Over 10 Years at Time of Fusion Preoperative Correction				
				Over 20 Degrees			Under 20 Degrees	
	Number	Curve Did Not Progress	Curve Did Progress	Number	Curve Did Not Progress	Curve Did Progress	Curve Did Not Progress	Curve Did Progress
Idiopathic (51 Cases)								
Main lumbar	0	0	0	5	0	5	0	0
Thoracolumbar	3	0	3	7	1	2	4	0
Combined thoracic and lumbar	3	0	3	9	1	5	1	2
Main thoracic	9	2	7	15	4	4	4	3
Paralytic (43 Cases)								
Main lumbar	1	1	0	6	0	5	0	1
Thoracolumbar	4	3	1	13	3	8	2	0
Combined thoracic and lumbar	0	0	0	4	0	0	4	0
Main thoracic	4	0	4	9	1	5	2	1
Total C curves	0	0	0	2	0	2	0	0
Congenital (23 Cases)	7	4	3	16	1	7	6	2
Total	31	10	21	86	11	43	23	9

stabilized. This occurred at about fourteen years of age in patients in whom fusion was performed before maturity of the skeleton. In patients over fourteen years, pseudarthrosis

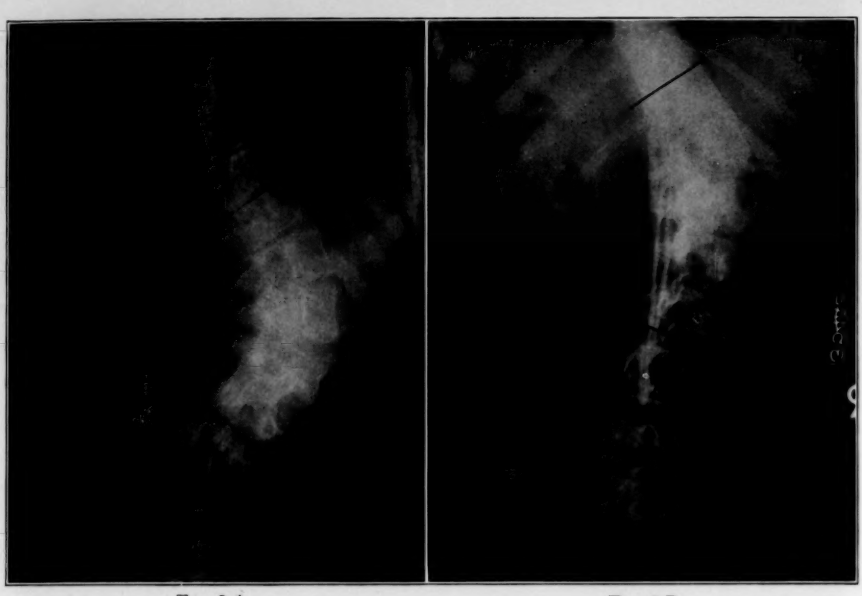

FIG. 2-A FIG. 2-B

Fig. 2-A: E. S., a seventeen-year-old girl, had an idiopathic lumbar curve. The curve was corrected to 51 degrees and the spine was fused from tenth thoracic vertebra to sacrum.
Fig. 2-B: Six months after fusion, no pseudarthrosis was present.

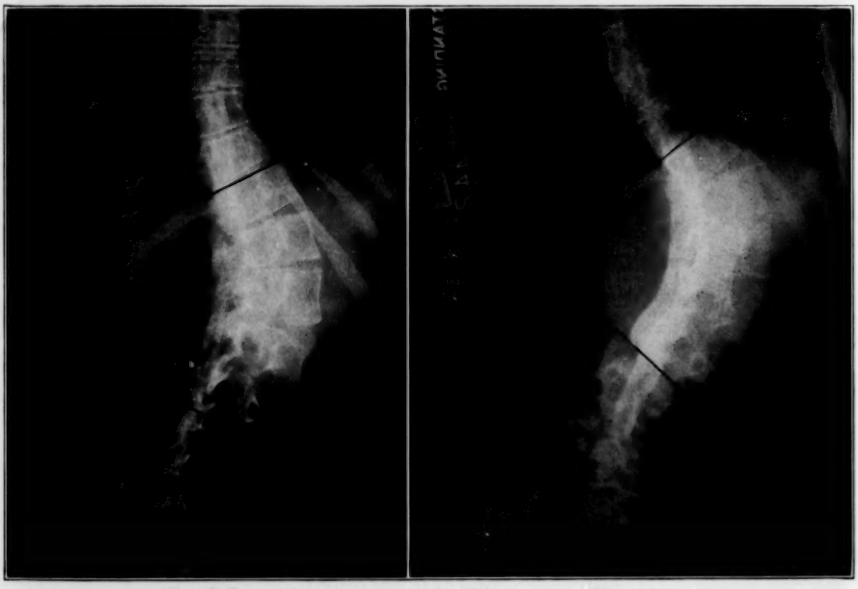

FIG. 2-C FIG. 2-D

Fig. 2-C: One year after fusion, several pseudarthroses could be seen.
Fig. 2-D: Four years after fusion. There was spontaneous closure of pseudarthroses in upper lumbar spine; those in lower lumbar spine persisted. Curve regressed to its preoperative size.

FIG. 3-A

FIG. 3-B

FIG. 3-C

Fig. 3-A: M. H., a girl of ten years and six months, with congenital scoliosis.

Fig. 3-B: Curve was partially corrected and spine was fused from first to twelfth thoracic vertebrae.

Fig. 3-C: Five years and two months after fusion, graft appeared solid on the concave side of the curve. It had disappeared from the tenth to twelfth thoracic vertebrae, where it was on the convex side of the counter curve.

FIG. 4-A

FIG. 4-B

FIG. 4-C

FIG. 4-D

Fig. 4-A: N. H., a girl of eleven years and four months, who had had anterior poliomyelitis at nine and one-half years, with weakness of abdominal and back muscles.
Fig. 4-B: Curve was corrected and spine was fused from the ninth thoracic to fifth lumbar vertebrae.
Fig. 4-C: Two years after fusion. Pseudarthroses developed only between fourth and fifth lumbar segments. In spite of the absence of pseudarthrosis above this level, curve increased and graft bent.
Fig. 4-D: Eight years after fusion. There had been progressive bending of graft and increase of curve.

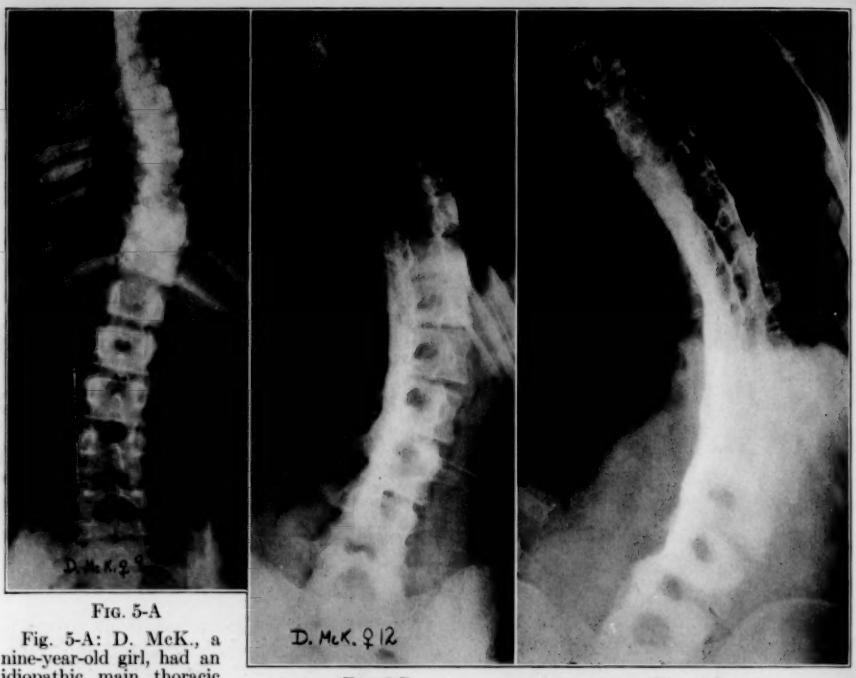

FIG. 5-A

FIG. 5-B

FIG. 5-C

Fig. 5-A: D. McK., a nine-year-old girl, had an idiopathic main thoracic curve, first noticed one year earlier. Spine fusion was performed at the age of ten years, from fifth thoracic to fourth lumbar vertebrae.

Fig. 5-B: Two years after spine fusion. The deformity had increased with addition to the main curve of the fused vertebrae outside it. No pseudarthrosis was present, but the graft bent.

Fig. 5-C: Eight years after spine fusion, showing extent to which curve had progressed.

often appeared when the scoliotic spine was fused after correction. This was followed by an increase in the spinal curvature until it approached its original size. Spontaneous closure of the pseudarthrosis then occurred (Figs. 2-A to 2-D).

The Graft

An effort was made to determine on the roentgenograms when the bone grafts appeared to be completely replaced by new bone. This determination was difficult, but in most of the patients it could be estimated that the bone grafts were replaced in from three months to one year. More time was required for substitution of large tibial cortical grafts than for grafts or chips of cancellous bone. However, a long time was required for the spongy bone to form a firm fusion. After a Hibbs fusion, about fourteen months elapsed before dense bony union could be seen on the roentgenograms.

The graft on the concave side of the curve became very dense and thick; the graft over the convex side was atrophied and in some cases disappeared (Figs. 3-A, 3-B, and 3-C).

In many instances the correction of spinal curvatures was lost a few months after removal of the immobilizing plaster cast. This loss of correction was often associated with visible pseudarthrosis of the grafted area. However, progressive bending of dense grafts was observed in several cases in which the scoliosis increased without visible pseudarthroses (Figs. 4-A to 4-D).

An increase in the deformity was noted after fusion in some cases with a progressive single curve, where the fusion included many vertebrae above or below the main curve. The rotatory force of the main curve was transmitted to the fused vertebrae above and below, and these vertebrae became incorporated in the curve (Figs. 5-A, 5-B, and 5-C).

The Non-Fused Segments of the Spine

In forty-two of the cases in which fusion was carried out before the patient was fourteen years of age, there was a measurable non-fused segment of the spine which averaged seven vertebrae. This segment invariably grew in length. The amount of growth depended, of course, upon the age of the patient at the time of the spine fusion. The intervertebral spaces immediately above and below the fused segment were often slightly wider than normal, because of the greater range of motion which necessarily took place at these points.

In some instances an enormous translatory shift occurred at the intervertebral space just above the fused area, and a sharply angulated curve developed. Similar angular deformities were seen less frequently at the lower end of the fused spinal segment. These sharp angulations often occurred when the grafting procedure did not extend to the ends of the main curve (Figs. 6-A and 6-B). They were frequently seen in cases of paralytic scoliosis, in spite of extensive fusion.

EVALUATION OF SPINE FUSION IN SCOLIOSIS

The evaluation of any treatment of scoliosis is difficult, since in many cases arrest of the curvature is spontaneous and not due to treatment [1].

The long-range results of surgical fusion for scoliosis in this Clinic have been disappointing on numerous occasions. In Table I, the cases are classified according to the

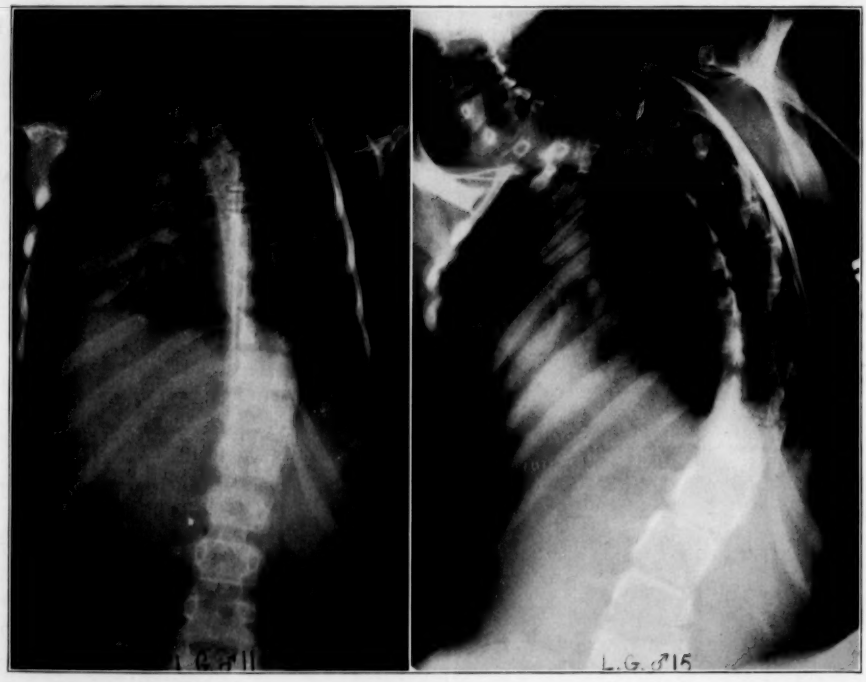

FIG. 6-A FIG. 6-B

Fig. 6-A: L. G., an eleven-year-old boy, had had anterior poliomyelitis at the age of seven years with residual involvement of back and abdominal muscles, and right lower extremity. Curve extended from second thoracic to first lumbar vertebrae. Spine fusion was performed at eleven years of age from fifth thoracic to second lumbar vertebrae.

Fig. 6-B: Four years after spine fusion. As the fusion did not extend to the upper end of the curve, there had been collapse above the fused segment.

etiology and pattern of the curvature. The final angular values of the curves have been tabulated as follows: curves over 80 degrees (very severe); curves measuring between 60 and 80 degrees (severe); curves of from 40 to 60 degrees (moderate); and curves under 40 degrees (mild).

The results in each group are analyzed in detail in Table II. The cases in which fusion was performed at or under ten years of age were studied as a separate group, in order to determine the results of early spine fusion. The curves had been corrected before operation in the majority of these cases. The cases in which fusion was done after the patient was ten years of age were divided into two groups, depending upon the degree of preoperative correction obtained: first, those in which the curve had been corrected more than 20 degrees before operation; and, second, those with less than 20 degrees of preoperative correction or with no correction. The scoliosis was stationary at the time of spine fusion in a great number of the cases in the second group, and credit should not be given to the fusion for the lack of progression.

Idiopathic Scoliosis (Fifty-one Cases)

Main Lumbar Curves

The five patients in this group were all over the age of thirteen at the time of fusion, and moderate to good correction was obtained in each case. Pseudarthrosis occurred at several sites in all cases, with complete loss of correction. Lumbar curves, then, were not benefited by surgical fusion.

Thoracolumbar Curves

Of the ten patients in this group, three had fusion at the age of ten years. The scoliosis progressed to final angular values of over 80 degrees in all three. Several pseudarthroses developed in two of these cases. In the third case the area of fusion was extensive; the graft bent; and the fused vertebrae outside the main curve became incorporated in the curve.

Seven patients had fusion after the age of twelve years. Good preoperative correction of the curve had been obtained in three cases. The correction was maintained in one of these, in which there was massive fusion of the curve plus one vertebra above and below; pseudarthrosis and loss of preoperative correction occurred in the other two cases. The fusion extended down to the sacrum in one and to the upper thoracic region in the other.

Four patients were between fifteen and nineteen years of age at the time of spine fusion, which was done without appreciable preoperative correction. The curve in each case was stationary before operation and remained unchanged.

Combined Thoracic and Lumbar Curves

The fusion in most of the twelve cases in this group was, necessarily, very extensive, including the thoracic and lumbar spine. Pseudarthrosis occurred in all cases between one or more pairs of segments of the lumbar spine and, in three cases, in the lower thoracic spine.

Three patients had fusion before the age of eight years. In all of these, increase to deforming proportions could have been expected from non-surgical therapy, because of the early onset. Most of the preoperative correction was lost. The final angular values in two were between 60 and 80 degrees; the third measured over 90 degrees.

In nine cases, fusion was done after the patient was eleven years of age. In three, no preoperative correction had been attempted. In two of these, in which fusion was carried out when the patient was twelve years of age, the curves progressed in spite of the fusion. In the other case, with a mild curve, fusion was done when the patient was seventeen years of age and there was no postoperative change. Five patients had preoperative correction, all of which was lost. In one case, in which fusion was done when the patient was sixteen years of age, correction was maintained.

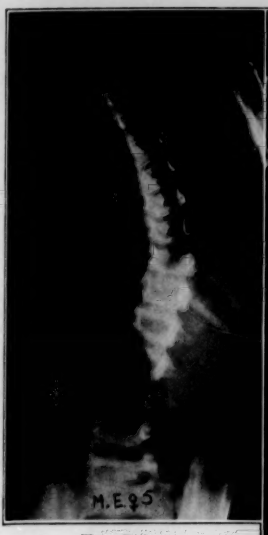

FIG. 7-A

FIG. 7-B

FIG. 7-C

Fig. 7-A: M. E., a five-year-old girl, had idiopathic scoliosis, with apex at tenth thoracic vertebra. Curve was corrected and spine was fused from fifth to twelfth thoracic vertebrae.

Fig. 7-B: Seven months after fusion.

Fig. 7-C: Nine and one-half years after fusion, the curve had not progressed. Fused segment did not grow in length.

Fig. 7-D: Preoperative photograph, at five years of age.

Fig. 7-E: Photograph of patient at fourteen and one-half years of age.

Fig. 7-F: Because of early spine fusion, patient had lordosis of the thoracic spine.

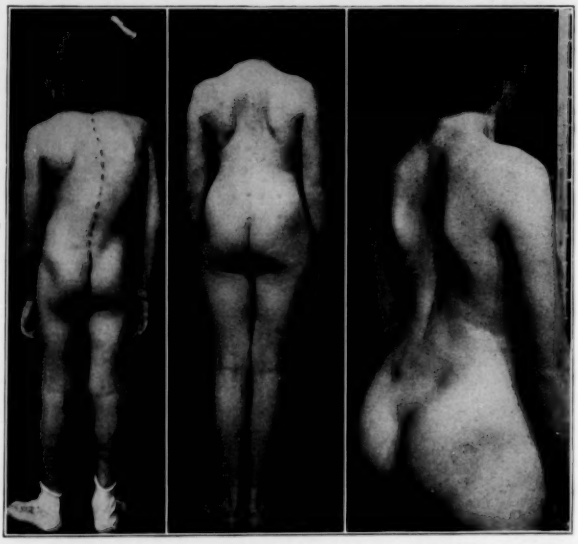

FIG. 7-D FIG. 7-E FIG. 7-F

Main Thoracic Curves

Twenty-four patients with main thoracic curves had fusion, nine before the age of ten years. In seven, correction had been obtained but was not held, the final angular values in all being over 80 degrees. In two cases in which fusion was done when the child was five years of age, good correction was maintained. In both, only the main curve and one vertebra above and below it were included in the fused segment. Pseudarthrosis did not occur in these two cases (Figs. 7-A to 7-F).

In fifteen cases, fusion was performed after the patient was ten years of age. Four had obtained preoperative correction, but maintained none of it. All of these fusions

FIG. 8-A FIG. 8-B FIG. 8-C

Fig. 8-A: V. E., a twelve-year-old girl, had had anterior poliomyelitis at seven years of age, with moderate weakness of upper abdominal muscles. Scoliosis was first noticed at eleven years of age. Correction of the curve and spine fusion were performed at twelve years, from fifth thoracic to second lumbar vertebrae.
Fig. 8-B: Six months after fusion.
Fig. 8-C: Three years after spine fusion. Most of the correction was maintained.

included more than twelve vertebrae, and many pseudarthroses developed in each case.

Four other curvatures were corrected preoperatively and most of the correction was maintained. In one of these, a long fusion was done and pseudarthroses developed in all of the lumbar vertebrae. The other three patients had fusion of the thoracic curve only. In only one did pseudarthrosis appear.

Seven patients had no preoperative correction. In four, with fusion after fifteen years of age, there was no postoperative increase of the curve, since the condition had been stationary before fusion. The other three patients were under thirteen years of age at the time of fusion, and in all the scoliosis increased to final angular values of over 90 degrees, in spite of fusion. All had pseudarthroses as well.

Paralytic Scoliosis (Forty-three Cases)

Main Lumbar Curves

Seven patients with paralytic lumbar curves had fusion. In one patient with mild asymmetrical involvement of the abdominal muscles and of the right lower extremity, the operation was performed at seven years of age, one year after acute anterior poliomyelitis. There was late, but complete, recovery of all the involved muscles. A mild lumbar curve was fused after complete correction and did not increase, in spite of pseudarthrosis between the fourth and fifth lumbar segments.

The remaining six patients had fusion after they were twelve years of age. The preoperative correction was lost in all instances. Several pseudarthroses appeared in each of the cases.

Thoracolumbar Curves

Seventeen thoracolumbar curves were fused. All patients in this group had paralysis of the abdominal muscles, and a few had asymmetrical involvement of the lower extremities.

In four cases, spine fusion was performed at or before the age of eight years, following correction. In three cases the curve did not increase over the corrected value. Pseudarthroses did not appear in these cases. The remaining patient showed marked increase of the curve and had pseudarthrosis.

Of thirteen thoracolumbar curves due to paralysis, fused after the patients were twelve years of age, good preoperative correction was obtained in eleven. In three of these, most of the correction was maintained after operation. Pseudarthrosis developed in all three, but only at the lower lumbar segments. In the remaining eight cases, in which the curves had been corrected preoperatively, the deformity recurred and in some cases increased to even greater angular values. Apical pseudarthroses were seen in half of these cases.

Two patients with paralytic thoracolumbar curves had spine fusion performed without preoperative correction. In neither one did the deformity increase after operation, but both were over sixteen years of age at the time of fusion.

Combined Thoracic and Lumbar Curves

The four cases in this category all had fusion after the patients were twelve years of age. A slight degree of preoperative correction was obtained in each case. The curves returned to their preoperative values, but did not progress beyond.

Pseudarthrosis of the lumbar segments appeared in three of the cases, in one of which pseudarthrosis also developed at the apex of the thoracic curve. No pseudarthrosis was visible in one case.

Thoracic Curves

Paralytic thoracic curves were fused in thirteen instances. In four of these patients, who were under nine years of age at the time of fusion, the curves increased to deforming extents. Pseudarthroses appeared in several sites in all of these cases.

Nine patients were over ten years of age when spine fusion was performed. In one patient with moderate weakness of the abdominal and back muscles, correction was maintained following fusion (Figs. 8-A, 8-B, and 8-C). In five other cases, in which the curvature was corrected before operation, the correction was not maintained.

Three additional cases had fusion without prior correction. There was no progression of the deformity in two patients, both of whom were over fourteen years of age at the time of fusion. The curvature increased considerably in the third case, in which fusion had been performed when the child was eleven years of age.

Pseudarthrosis was seen in all patients with paralytic thoracic curves, except the three in which the curve did not increase postoperatively.

Total Curves

Two patients with very extensive muscle involvement developed total C curves; fusion followed preoperative correction. In both cases the correction was lost and pseudarthroses appeared.

Congenital Scoliosis (Twenty-three Cases)

No consistent curve patterns were found in congenital scoliosis, since the deformity was due to vertebral and rib anomalies which may occur in any segment of the spine. Therefore, the cases were all grouped together.

Seven patients with curvatures due to congenital spine deformities had fusion before the age of ten years. In four cases, all with one or more hemivertebrae as the major anomaly, the curve did not progress. Of the three patients with progression following fusion, two had extensive spina bifida and the third had several wedged vertebrae.

In sixteen cases, fusion was done after the children were ten years of age. Eight of these curvatures had been corrected before operation. One, a mild curve due to a wedged vertebra, did not increase. The other seven did increase; one patient had very extensive spina bifida, and the others had several wedged vertebrae.

Eight cases had fusion without correction. In six of these, with fusion after the age of thirteen years, the deformity did not progress postoperatively; in two patients, who were twelve years of age at the time of spine fusion, the curve increased slightly.

DISCUSSION

The study of scoliosis treated by spine fusion in patients under fourteen years of age shows that the fused segment of the spine did not grow appreciably in length in the majority of cases. Slight growth took place in twenty-five cases, in which pseudarthrosis developed. Some growth in height of each vertebra within the fused segment occurred, but this was at the expense of the intervertebral spaces, which became narrower. Fusions which included most of the spine in children under ten years of age led to severe shortening of the torso and thoracic lordosis.

Pseudarthrosis was common in the most mobile segments of the spine. It was almost always present when the entire lumbar spine had been fused, and was seen much less commonly after fusion of the thoracic spine alone. The tendency to pseudarthrosis in the lower lumbar spine was so great that, in one case, five attempts at re-fusion failed. Spontaneous bony union of pseudarthrosis in the thoracic and upper lumbar spine was seen in some cases when the curve became stabilized.

The method of spine fusion did not appear to influence the results in our cases, although the use of massive amounts of bone for grafts added stability to the fusion. However, a bone graft is a living structure after it has been organized, often yielding to the deforming forces produced by the scoliotic spine, if these are of sufficient strength. The structure of the bone graft changes with the strains and stresses acting upon it, becoming denser in some places; in others it is atrophic or even disappears. The final thickness and

configuration of the graft are not reached for several years. Extensive fusions in our cases have failed, even in the absence of pseudarthrosis, because of bending of the graft. This was particularly true when concave-side fusions were performed in young, growing patients. This type of fusion seemed to enhance the progression of the curve in some cases by preventing vertebral growth on the concave side, while permitting the convex side to expand.

As regards the extent of the fused segment, short fusions of thoracic and thoracolumbar patterns, which included the main curve and one vertebra above and below, appeared to be the most satisfactory. When the fusion was extended to include many vertebrae above and below the main curve, increase in the deformity occurred. This increase was associated either with pseudarthrosis, with bending of the graft, or with the addition to the main curve of the fused vertebrae outside the curve. On the other hand, if the fusion did not extend to the ends of the main curve, collapse of the curve occurred immediately above or below the fused segment.

The results of spine fusion in idiopathic scoliosis were encouraging in a few cases with main thoracic curves, which offer poor prognosis under conservative treatment. Two patients who had fusion before five years of age were probably saved from severe deformity by fusion of the curve only, plus one vertebra above and below. Fusions of similar extent were also successful in patients operated upon after ten years of age. Most of the failures occurred in the cases in which extensive segments of the spine had been fused.

A good result was obtained in an idiopathic thoracolumbar curve when massive bone grafts were used. The failures in cases of this curve pattern occurred when fusion was performed at an early age, or when it was very extensive.

Fusions of idiopathic main lumbar curves failed in the authors' series. As these curves are not very deforming, fusion is probably not warranted.

Surgical fusion of the idiopathic combined thoracic and lumbar curves did not benefit a majority of the patients. Since the curves in this group are usually well compensated and body alignment is well maintained, surgery is rarely indicated. Where attempts were made to maintain correction of both the thoracic and lumbar curves, fusion of most of the spine was necessary. This led to pseudarthrosis and subsequent loss of correction. Correction and fusion of only one curve brought about decompensation with increase of the deformity.

In paralytic scoliosis, fusion produced good results in thoracolumbar curves. These curves were usually associated with abdominal weakness. The successful cases were those with minimal involvement of other muscle groups. Here, again, fusion of the curve area only gave the best results.

Correction was lost in all fused paralytic lumbar curves except one, in which muscle recovery took place. As in lumbar curves of the idiopathic group, motion of the lumbar spine favors pseudarthrosis and loss of correction.

Paralytic combined thoracic and lumbar curves were rare and were not benefited by surgery.

Paralytic main thoracic curves were usually very extensive and were associated with severe muscle weakness. Fusion of corrected thoracic curves failed in all cases, except one in which muscle involvement was moderate. These curves are usually very deforming, and spine fusion did not appear to benefit many of them.

Total C curves were seen in patients who were confined to a chair because of extreme muscle weakness. These curves were easily corrected, but the correction was not maintained by spine fusion.

In congenital curvatures, the results of fusion seemed to be related to the type of vertebral anomaly. In cases with extensive spina bifida or with many wedged vertebrae, the abnormality increased in spite of early spine fusion, and correction was not maintained when fusion was carried out at a later age. On the other hand, good results were seen in

cases with one or even several hemivertebrae. However, many of these curves are not progressive.

SUMMARY

1. Of 117 cases of scoliosis treated by spine fusion, the growth of the fused segment of the spine in young patients was absent or minimal except when pseudarthrosis occurred.

2. Pseudarthrosis was related to the mobility of the fused spinal segment and to the extent of the fusion. It was very common in fusions of the lumbar spine, but infrequent in fusions of the thoracic spine alone. Spontaneous closure of the pseudarthrosis was often observed when the scoliosis became stabilized.

3. In idiopathic thoracic and thoracolumbar and paralytic thoracolumbar curve patterns, short fusions of the main curve and one vertebra above and below it gave the most satisfactory results.

4. Increase of the scoliosis following spine fusion was seen when the fused area was either too long or too short. In extensive fusions, increased scoliosis was associated with pseudarthrosis, bending of the graft, or with the addition of more vertebrae to the curve. Where fusion did not reach the ends of the curve, increase occurred above or below the fused segment.

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2. Steindler, Arthur: Orthopedic Operations: Indications, Technique and End Results. Springfield, Illinois, Charles C. Thomas, 1940.

DISCUSSION

Oxidized Cellulose and Cortisone to Prevent Bone Formation

(*Continued from page 750*)

In regard to the excision of the capsule, originally there was a fifth group but, because of the inadequate number of dogs used, I did not report it. Like Dr. Key, I excise the capsule in all arthroplasties of the hip, according to Dr. Smith-Petersen's teaching. We do have two dogs in which I had completely excised the capsule all the way around so as to simulate the condition in the human being. I sacrificed one of these dogs last week and the same lack of fibrous-tissue formation was found. I do not have the pathological specimens on that one dog. There was, however, no evidence of fibrous-tissue formation, and the anatomical planes of muscles opened up easily. The joint was more mobile where we had resected the capsule than where we had resutured it.

Dr. Key mentioned that the skin healed with a subcutaneous cavity. Because of this finding, the injection of systemic cortisone has been withheld until the dermal layers of the skin have healed—seven to ten days after operation—and the skin sutures are not removed for fourteen to eighteen days after operation. The cortisone injected into the arthroplasty site inhibits the formation of connective tissue locally, but not at any distance from the area of direct contact.

As far as extrusion of oxidized cellulose is concerned, we have had one case where the wound extruded it. That was a technical error on my part. Too much was used, as we tried to do too good a job. I think one must be very careful in inserting it and be sure not to use too much. About three layers should be used; about three grams will be required in the average hip arthroplasty.

LEGG-PERTHES DISEASE

A Method for the Measurement of the Roentgenographic Result

BY CLARENCE H. HEYMAN, M.D., AND CHARLES H. HERNDON, M.D., CLEVELAND, OHIO

From the Department of Orthopaedic Surgery, University Hospitals, Cleveland

During a study of the results of treatment of Legg-Perthes disease, the need was recognized for a more precise appraisal of the roentgenographic results than can be expressed by the usual terms of normal, good, fair, and poor. These categories are not clearly defined, and are subject to considerable differences in interpretation. It would be of great advantage if results could be classified impartially and objectively by independent observers to permit a corresponding result being placed in the same category. A uniform rating, to minimize the personal equation, would be of considerable value for comparative statistical studies.

Although falling short of meeting this need, a method has been evolved which helps to resolve a general impression of abnormality of anatomical configuration to a measurable basis. It consists in comparing the measurements of all important components of the deformity with similar components of the structure of the normal hip, and expressing the result as a comprehensive quotient. This has been of great assistance in evaluating the roentgenographic picture of the hip as a whole, and perhaps may serve as an approved means of expressing the roentgenographic result in Legg-Perthes disease.

Eyre-Brook measured the deformity as the index of the height of the epiphysis to its width. Since this varies, he says, between 45 and 55 in the normal child under seven years of age, and between 35 and 45 in individuals over seven years of age, it is obvious that there may be considerable flattening of the epiphysis with the index still within normal limits.

Sjövall expressed the deformity as the quotient of the epiphyseal index with that of the normal hip on the other side. This is an improvement; but it still does not represent the complete picture, since it takes into account only one of the components of deformity. For example, as will be illustrated, the epiphyseal quotient alone may suggest a rating of only 72 per cent. of normal, but the whole picture of the roentgenogram may deserve a better rating.

Levy and Girard studied the roentgenographic results for the amount of flattening of the head and broadening of the neck, but their recordings of the results are in terms of the height of the epiphysis only as compared with the normal side. The amount of head coverage by the acetabulum and the shape or the obliquity of the roof of the acetabulum were not taken into consideration. No single quotient is sufficient to evaluate the complete picture.

The deformity resulting from Legg-Perthes disease consists of any or all of several components. The epiphysis is commonly flat and broad, and may expand beyond the acetabulum. The neck may be correspondingly broad and also short. With more severe deformity, an enlarged head may be inadequately covered by a supporting acetabular roof, which subsequently becomes worn to an obliquity, making the acetabulum broad and relatively shallow. All of these relations are important in considering the functional capacity of the hip. Although more or less flattening of the epiphysis is present in any case of deformity, this is not necessarily the dominating and most important feature. No single component of deformity is characteristic of all old cases of Legg-Perthes disease. It is proposed, therefore, to express the picture of the shape of the head, neck, and acetabulum as a comprehensive quotient, as being more truly indicative of any abnormality of the anatomical configuration of the articulation as a whole.

FIG. 1-A

Legg-Perthes disease six years after treatment. This hip would be accepted as normal, unless critically compared with the normal hip on the other side.

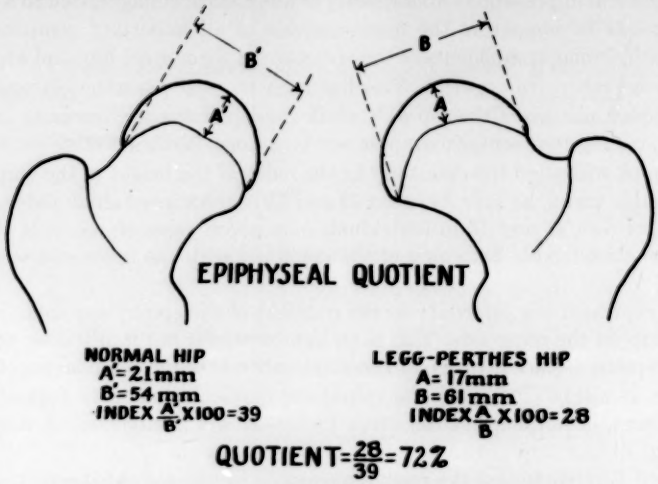


FIG. 1-B

A tracing of the head and neck of each femur to illustrate computation of the epiphyseal quotient. The result deserves a better grade than 72 per cent.

MEASUREMENTS OF THE QUOTIENTS

Figure 1-A, a roentgenogram taken six years after treatment, is used for illustrative purposes. The result is very good, and might be accepted as normal if the hip were not compared with the normal hip on the other side. One may critically call attention, however, to the flattening of the epiphysis as compared with that of the normal hip, and more rigidly grade the result as somewhere below normal. A comparison of the indices of similar components of the hip with those on the normal side will show how the result can be expressed as a comprehensive quotient.

Epiphyseal Quotient

The epiphyseal index is the proportion of the height of the epiphysis to the width at the epiphyseal line, and is used to measure abnormality of the shape of the epiphysis. In order to avoid a fraction, this is multiplied by 100. Figure 1-B is a tracing of the head and neck of both femora in Figure 1-A for illustrative purposes. In practice, tracings are not

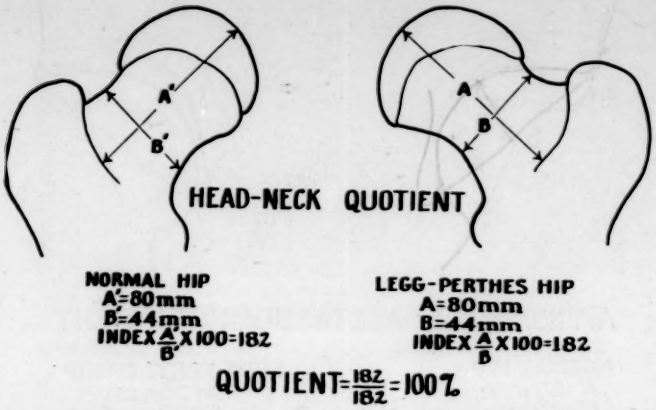


FIG. 1-C

The same tracing to illustrate computation of the head-neck quotient. In this case it is normal, or 100 per cent.

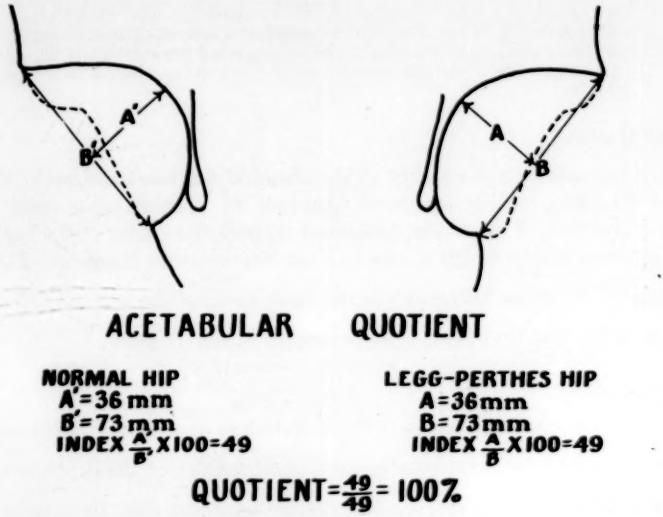


FIG. 1-D

A tracing of the acetabulum on each side to illustrate computation of the acetabular quotient. The acetabulum is normal, or 100 per cent.

recommended; measurements in millimeters can be made more accurately on the roentgenogram itself. In this case the epiphyseal index of the affected hip, $\frac{A}{B} \times 100$, is 28; the epiphyseal index of the normal hip, $\frac{A'}{B'} \times 100$, is 39. The quotient, $\frac{28}{39} \times 100$, is 72. If one were to consider the epiphysis only, this quotient could be interpreted as the hip being only 72 per cent. of normal. It would appear, however, that this hip is better than 72 per cent. of normal, which suggests only a fair hip. Other measurable manifestations of deformity are the proportion of the length of the head and neck to the width of the neck, the depth of the acetabulum in proportion to its width, and the extent of a supporting roof of the acetabulum over the head.

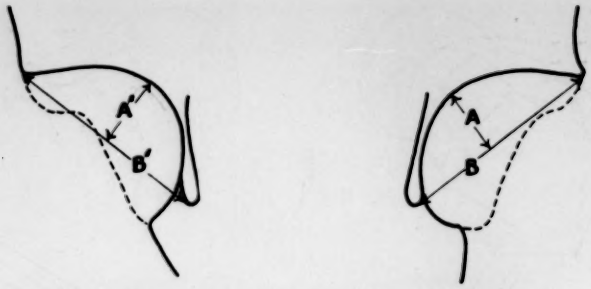


FIG. 1-E

The same tracing to illustrate computation of an approximate acetabular quotient when the lower border of the acetabulum is poorly defined. This does not measure the acetabular index accurately, but the quotient is not seriously in error.

Head-Neck Quotient

This is to measure abnormality of the shape of the head and neck. Figure 1-C is a tracing of the same roentgenogram to illustrate the proportion or index of the length of the head and neck of the femur, measured through the center of the neck to the intertrochanteric line, to the width of the neck at its narrowest diameter. The index of the affected hip, $\frac{A}{B} \times 100$, is 182, which is the same as $\frac{A'}{B'}$ of the normal hip. The quotient, $\frac{182}{182}$, is 100, indicating that there is no deformity in this respect.

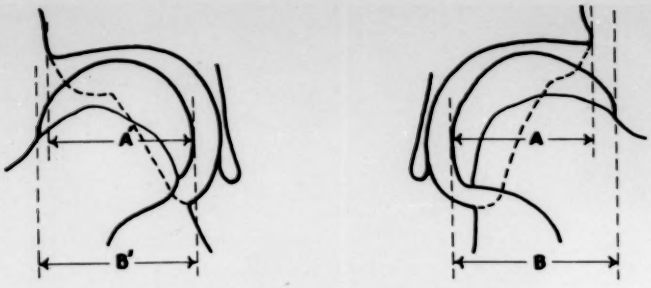
Acetabular Quotient

This is to measure shallowness of the acetabulum or obliquity of the roof. Figure 1-D is another tracing of the same roentgenogram. The index of the depth to the width in $\frac{A}{B}$ and $\frac{A'}{B'}$, measured in millimeters, is $\frac{36}{73} \times 100$, or 49 on each side. Here again, the quotient, $\frac{49}{49}$, is 100, indicating no abnormality in the shape of the acetabulum.

It may be difficult to measure the true acetabular index accurately in some roentgenograms, because the lower margin of the acetabulum is poorly defined. In most instances it can be identified closely enough, for comparative purposes, by noting the lower end of the posterior border where it joins the ischium. As a second choice, one may use the line from the upper margin of the acetabulum to the lower end of the tear figure as the base line. While this will not measure the true acetabular index, the quotient will remain approximately the same as for a measurement of the true acetabular index.* This does not apply, however, when there is a marked obliquity of the acetabular roof.

Figure 1-E is the same tracing as Figure 1-D, but illustrates the use of the line to the lower end of the tear figure, rather than to an estimated lower margin of the acetabulum, to determine the relative index in computing the quotient. Here the relative acetabular index of the affected hip, $\frac{A}{B} \times 100$, is 31; the relative index of the normal side, $\frac{A'}{B'} \times 100$,

* The true acetabular index has been determined by Le Damany as varying from 41.6 at birth to 60 or even 70 in an adult.



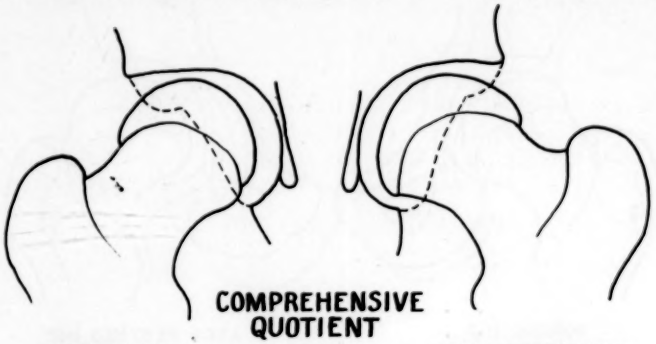
ACETABULUM-HEAD QUOTIENT

NORMAL HIP	LEGG-PERTHES HIP
A'=54mm	A=53mm
B'=58mm	B=61mm
INDEX $\frac{A'}{B'}$ X100=93	INDEX $\frac{A}{B}$ X100=87

$$\text{QUOTIENT}=\frac{87}{93}=94\%$$

FIG. 1-F

Tracing of the head in relation to the acetabulum at both hips to illustrate the measurement of the acetabulum-head quotient, or the head coverage. The two indices are within normal range, but the quotient is 94 per cent. of normal.



COMPREHENSIVE QUOTIENT

NORMAL HIP		LEGG-PERTHES HIP
	EPIPHYSEAL	72
	HEAD-NECK	100
	ACETABULAR	100
	ACETABULUM-HEAD	94
AVERAGE or COMPREHENSIVE		92% of NORMAL

FIG. 1-G

Tracing of the head and neck of each femur. The comprehensive quotient, 92 per cent., is the average of the other quotients, and is accepted as the grade of the result in the Legg-Perthes hip shown in Fig. 1-A.

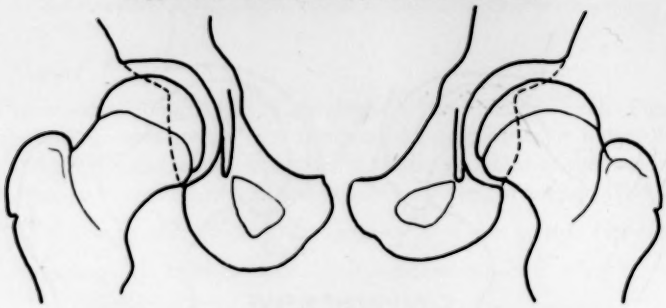
is 34. The quotient, then, is 91. There is some discrepancy, but it is not serious, since it will not alter the complete comprehensive grading by more than 2 per cent. Perhaps the quotient of obliquity of the roof could be measured most accurately by the proportion of a trigonometric function of the angle of obliquity on both sides, but this would be too complicated. Practically, the depth-width quotient accomplishes the same purpose.

Acetabulum-Head Quotient

This is to measure a disproportion of the size of the head in relation to the acetabulum, or lateral displacement of the head from the depth of the acetabulum. Figure 1-F is a tracing of Figure 1-A, showing the head in relation to the acetabulum, to illustrate the

FIG. 2-A

Legg-Perthes disease, seven years after treatment.



NORMAL HIP INDEX		QUOTIENT	LEGG-PERTHES HIP INDEX
EPIPHYSEAL	43	60	26
HEAD-NECK	177	88	155
ACETABULAR	48	100	48
ACETAB.-HEAD	81.4	86	70

COMPREHENSIVE QUOTIENT 83.5% NORMAL

FIG. 2-B

Tracing for analysis of the deformity, with individual quotients and comprehensive quotient. There is abnormality of all components of bony configuration except the acetabulum. The grade of the result is 83.5 per cent.

amount of expansion of the head beyond the supporting roof, or the amount of head coverage. Line A is a horizontal measurement from the innermost surface of the head to a vertical line projected from the outermost margin of the acetabulum; line B is a similar horizontal measurement from the innermost surface of the head to a vertical line projected from the outermost surface of the head. In this instance the index of the affected hip, $\frac{A}{B} \times 100$, is 87; that of the normal hip, $\frac{A'}{B'} \times 100$, is 93. The acetabulum-head quotient is $\frac{87}{93} \times 100$, or 94 per cent. This is good, but not normal.*

* From previous studies [4] of roentgenograms in cases of congenital dislocation of the hip, the normal head coverage has been found to be between 70 and 100 per cent., with an average of 90 per cent.

FIG. 3-A

Legg-Perthes disease, five years after treatment.

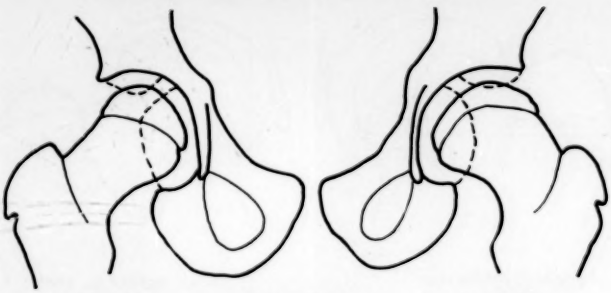


FIG. 3-B

Tracing, with individual quotients and comprehensive quotient. None of the components is normal. The comprehensive quotient is 78 per cent.

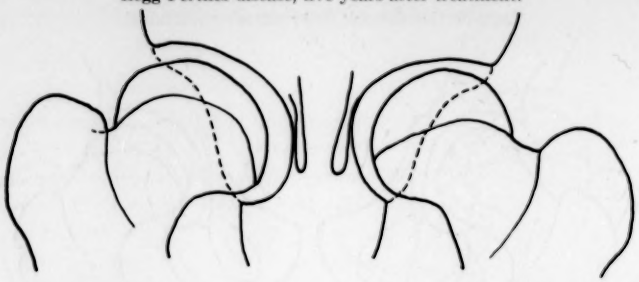
Comprehensive Quotient

Assuming that each of these components of deformity is of equal importance, the comprehensive or general picture of the hip is expressed as the average of the quotients (Fig. 1-G). In this case, it is 92 per cent. of normal, which is a more fitting expression of the good general appearance of this hip than the 72 per cent. grade obtained by considering the epiphysis alone.

Figure 2-A, the roentgenogram of another patient, taken seven years after treatment, also looks nearly normal, but not so good as Figure 1-A. How can one indicate the difference?

FIG. 4-A

Legg-Perthes disease, five years after treatment.



LEGG-PERTHES HIP INDEX		QUOTIENT	NORMAL HIP INDEX
EPIPHYSEAL	20	54	37
HEAD-NECK	150	79	190
ACETABULAR	25	78	32
ACETAB.-HEAD	81.4	85	88

COMPREHENSIVE QUOTIENT 74% NORMAL

FIG. 4-B

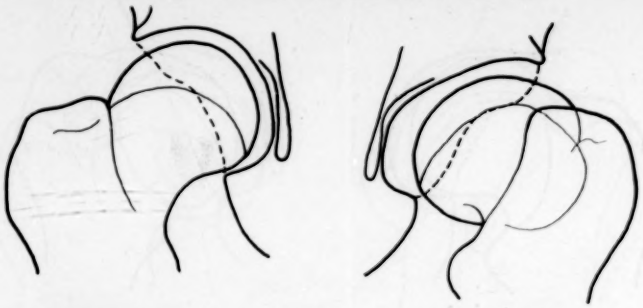
Tracing, with individual quotients and comprehensive quotient. This hip is graded 74 per cent.

The acetabulum appears normal, but the head is relatively broad and the neck is short. A tracing for illustrative purposes (Fig. 2-B) shows that the epiphyseal quotient is 60, the head-neck quotient 88, the acetabular quotient 100, and the head-coverage quotient 86. The average is 83.5 per cent. of normal, which seems to be a reasonably accurate grade for comparative purposes.

Figures 3-A and 3-B are the roentgenogram and tracing of the result in another patient, five years after treatment, and are not much different from Figures 2-A and 2-B. In this case, however, there is a slight obliquity of the acetabular roof, and the epiphysis is flatter. The epiphyseal quotient is 57, the head-neck quotient 86, the acetabular quotient 85, and the head-coverage quotient 85. The average is 78 per cent. of normal, which again appears a fitting expression for comparative purposes. Incidentally, the epiphyseal

FIG. 5-A

Legg-Perthes disease, twelve years after treatment.



NORMAL HIP INDEX		QUOTIENT	LEGG-PERTHES HIP INDEX
EPIPHYSEAL	35	57	20
HEAD-NECK	148	61	91
ACETABULAR	55.7	75	42
ACETAB.-HEAD	83	91	76

COMPREHENSIVE QUOTIENT 71% NORMAL

FIG. 5-B

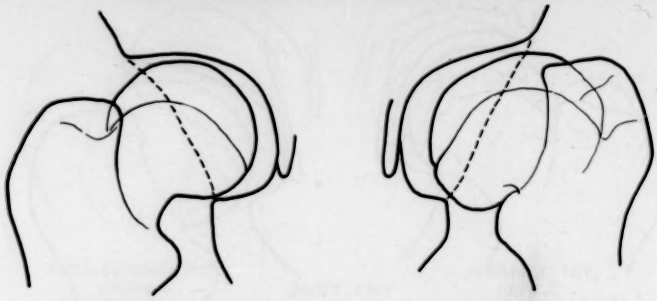
Tracing, with individual quotients and comprehensive quotient. The grade is 71 per cent.

quotient in this case is only 57 per cent., illustrating again that the epiphyseal index or quotient alone is not sufficient for estimation of the roentgenographic result. This hip impresses one as better than only 57 per cent. of normal; 78 per cent. is a more acceptable estimate.

Four more roentgenograms of progressively worse results have been analyzed (Figs. 4-A, 5-A, 6-A, and 7-A). These roentgenograms were taken five years, twelve years, fifteen years, and twenty years after treatment, respectively. The comprehensive quotient in Figure 4-B is 74 per cent.; in Figure 5-B, 71 per cent.; in Figure 6-B, 65 per cent.; and in Figure 7-B, 49 per cent.

FIG. 6-A

Legg-Perthes disease, fifteen years after treatment.



NORMAL HIP INDEX		QUOTIENT	LEGG-PERTHES HIP INDEX
EPIPHYSEAL	29.5	67	19.7
HEAD-NECK	191	61	117
ACETABULAR	61	65	40
ACETAB.-HEAD	88.5	68	60

COMPREHENSIVE QUOTIENT 65% NORMAL

FIG. 6-B

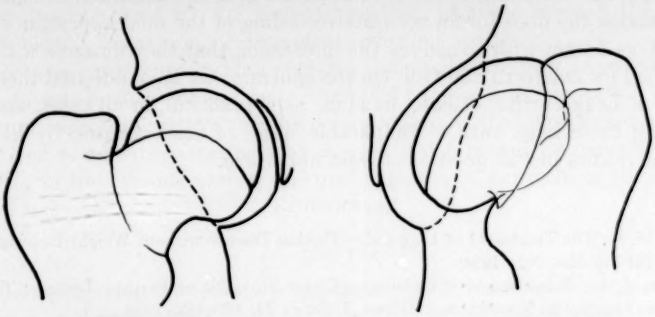
Tracing, with individual quotients and comprehensive quotient. A poor result, graded at 65 per cent.

The head-coverage quotient in Figure 5-B is quite high (91 per cent.), although the complete picture rates only 71 per cent. This shows once more that all components of the deformity enter into an evaluation of the general picture, and that no single index or quotient is a sufficient basis upon which to evaluate the result. The head of the femur may be quite well covered by the acetabular roof, but the general picture is that of a low-grade result.

A comprehensive measurement above 90 indicates an excellent to normal result; between 80 and 90, good; between 70 and 80, fair; between 60 and 70, poor; and below 60, a very poor to a bad result. These percentages immediately present to one who has not seen

FIG. 7-A

Legg-Perthes disease, twenty years after treatment.



NORMAL HIP INDEX		QUOTIENT	LEGG-PERTHES HIP INDEX
EPIPHYSEAL	34	50	17
HEAD-NECK	150	69	104
ACETABULAR	65.5	28	18.7
ACETAB.-HEAD	91	48	44

COMPREHENSIVE QUOTIENT 49% NORMAL

FIG. 7-B

Tracing, with individual quotients and comprehensive quotient. A very bad result, graded at 49 per cent.

the roentgenogram a better visualization of the true picture and a more objective interpretation than are obtained by a grading from normal to poor. Again, they are the commonly accepted grades representing excellence to failure.

The authors do not pretend, of course, that this analysis and recording of the result are complete or without fault. Anatomical configuration only is taken into account. In adults there may be little or no indication of where the epiphyseal line was, but here the head-neck quotient tends to neutralize an error in measuring the epiphyseal quotient. It has sometimes been found difficult to identify the lower border of the acetabulum in computing the acetabular index, but in this case one can direct the base line to the lower

end of the tear figure to determine the relative acetabular quotient. To overcome any uncertainty in measuring the true acetabular index accurately, a roentgenogram with the hip abducted and externally rotated, as for a lateral view of the neck of the femur, clearly defines the lower and upper margins of the acetabulum. Again, the absolute length and breadth of the neck of the femur cannot be measured, and particularly this may be difficult to estimate with the extremity in external rotation when the roentgenogram was made. The externally rotated position also distorts the picture, making measurement of the actual amount of head coverage inaccurate. Here again, however, we are concerned with relative measurements for comparative purposes rather than true indices. The errors in measuring the individual components of deformity tend to neutralize each other, not seriously affecting the comprehensive result. These difficulties can be largely eliminated by proper positioning of the patient for the roentgenogram.

A critical analysis of the five roentgenograms of cases reported by Danforth, where treatment consisted of prolonged non-weight-bearing, reveals that one hip appears normal, two are nearly normal, and two show considerable deformity. Gill presented five cases illustrated by roentgenograms in which treatment was considered adequate. An analysis of these illustrations shows that the epiphyseal quotient varied from 42 to 75 per cent. of normal. Gill's conclusion, that "treatment by rest in bed with Buck's extension leads to such complete restoration that in the final result it is difficult to detect any deformity of head, neck, and acetabulum", may be misleading to those who expect to obtain a normal hip in all cases by following this method of treatment. While the results are very good, they are not normal according to the evidence shown on the illustrative roentgenograms. This demonstrates the need for an accurate recording of the final appearance of the hip.

The authors do not wish to convey the impression that they disagree with the treatment prescribed by Danforth and Gill. On the contrary, we have adopted their principles of treatment of Legg-Perthes disease, in so far as is practical, in all cases, and intend to continue along these lines until a comparable series of cases treated by less confining methods show results just as good or at least not worse.

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SLING PROCEDURE FOR CORRECTION OF SPLAY-FOOT, METATARSUS PRIMUS VARUS, AND HALLUX VALGUS *

BY ROBERT J. JOPLIN, M.D., BOSTON, MASSACHUSETTS

THE PROBLEM

A survey, in 1947, of the end results of operations for hallux valgus at the Massachusetts General Hospital[5] revealed that the Keller operation, employed for the most part up to that time, hardly gave satisfactory results. Similar observations have been made recently by Cleveland and Winant. Of the various standard procedures used in the 1947 series, the Keller operation had been employed in 66 per cent.

The conclusions from that study were: The Keller operation does not restore that degree of strength of the great toe which is essential to normal locomotion. It does not effect a significant correction of the mechanical faults that usually coexist in the foot as a whole. There is good evidence that it throws upon the rest of the foot a burden as great as, or even greater than, that imposed by the deformity for which the operation had been performed. Its value, therefore, is limited and is, in large measure, local.

The following unsatisfactory results were found repeatedly:

1. The reconstructed push-off mechanism either appeared weaker after operation than before or was unchanged in 89 per cent. of the cases; this condition was due to weakness of the flexor mechanism of the great toe. The tendency to splay-foot either was unchanged or was increased by the Keller operation. Calluses beneath the heads of the metatarsals usually became more prominent following operation.

2. Ninety-one per cent. of those operated upon failed to show improvement in structure of the foot as a whole; 67 per cent. continued to wear arch supports.

3. Inquiry regarding return to employment disclosed that 90 per cent. of the patients were employed in sedentary occupations or work which permitted periods of sitting.

4. Varus of the first metatarsal was unchanged in 90 per cent. of the cases; in 9 per cent. it had increased.

THE PLAN

In order to develop an operative technique which would give more satisfactory results, experimental corrective procedures were first carried out on amputated limbs. The advantage of utilization of the adductor hallucis, as first suggested by McBride[3] in 1928, seemed obvious. When this muscle had been removed from its insertion, its tendon proved to be so long that it could reach across the neck of the first metatarsal. Therefore, to enable this muscle to function effectively, it seemed physiologically sound to attach it to some structure on the medial rather than on the lateral aspect of the first metatarsal for, as Wright has said: "The greater the *initial length* of skeletal muscle fibers, the greater is the energy liberated during isometric contraction and the greater the amount of work realized during isotonic contraction . . ." Bechtol stressed this point with his statement: "The degree of tension that can be developed is definitely related to the length of the muscle at the time it contracts. An appreciation of this relationship between length and tension is important in surgery involving lengthening, shortening, or transplanting of muscles." Bechtol also noted: "Von Schwan's law states that the muscle progressively loses strength as its length is allowed to shorten".

Consequently, in the procedure here described, a drill hole is made through the shaft to permit the attachment of the adductor hallucis tendon to the capsule on the tibial side. This permits the transplanted muscle to lie in such a position that it will have adequate

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 16, 1950.

length to enable it to function most effectively. This differs from McBride's operation, in which he attached the "conjoined adductor tendon" to the lateral aspect of the neck, permitting the muscle to remain more or less relaxed.

To prevent the adductor hallucis, even though it might appear strong, from suddenly overstretching, some reliable method was needed to overcome temporarily the splay or spreading forces exerted by the soft tissues, which had for years been adjusted to the deformity. The logical structure seemed to be the long extensor tendon of the fifth toe.

When this tendon had been divided as far proximally as possible, it was not only sufficiently long to reach across the sole of the foot, but there was an inch or more to spare. Furthermore, the tendon was so strong that, when both ends were rolled up on Kelly forceps, it was practically impossible to break it by manual traction.

The distal portion of this tendon was anchored securely to the neck of the fifth metatarsal, while the little toe was held in neutral position. (This affords an excellent opportunity to correct any malposition of the fifth toe.) The tendon of the abductor digiti quinti was then brought upward and sutured to the extensor of the fifth toe, distal to the tenodesis. This served as a positive muscle stabilizer to replace the tenodesis (should the transplanted tendon ever become stretched), and thus prevented permanent flexion of the little toe. After operation, the fifth toe appeared to move adequately with the other toes during flexion and extension.

The next step was to adapt to the living foot a method which had appeared satisfactory for correction of foot deformities on the cadaver. Certain cardinal principles of any sound orthopaedic operation had to be fulfilled,—namely (1) respect for anatomy and physiology; (2) dissection confined to fascial and muscle planes, cutting across or destruction of important structures being avoided; and (3) speedy restoration to normal function. With these rules in mind, the first operation, which was referred to by the house officers as the "sling procedure", was performed in October 1947. Since that time, deformities in 131 feet have been corrected by this method.

In these cases the strength of the great toe, which is essential for normal locomotion or "take-off", was not weakened. When considered as a whole, the foot appeared stronger. Most of the patients were able to wear a narrower shoe than formerly and to return to occupations requiring long periods of standing or walking. Varus of the great toe and splay-foot were improved in the majority of the cases; arch supports and foot cuffs were usually discarded.

FIG. 1

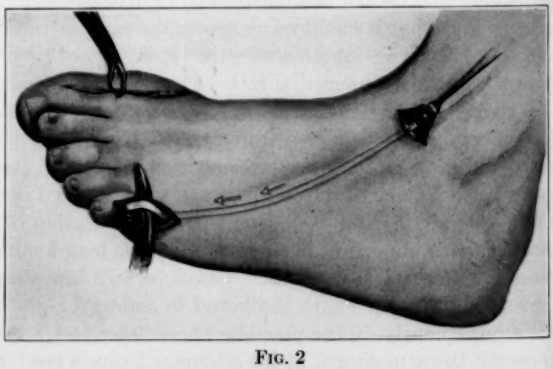

FIG. 2

Fig. 1: The adductor hallucis tendon is separated from the flexor hallucis brevis, its lateral sesamoid, capsule, and proximal phalanx.

Fig. 2: The first skin incision is temporarily closed over a wet saline sponge, while the transplant of the fifth extensor tendon is prepared.

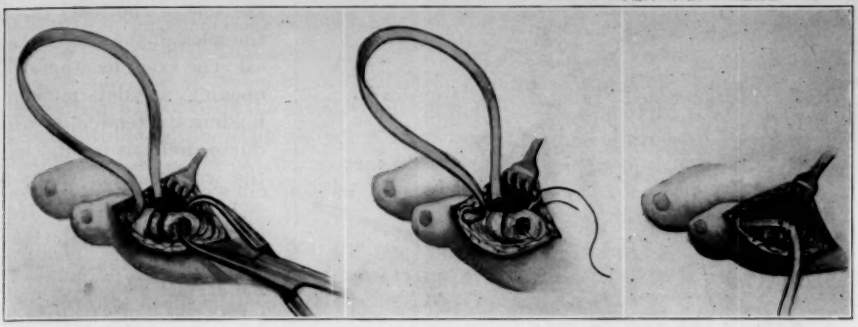

FIG. 3

A towel clip serves adequately to make an opening through which the silk suture passes, to hold the extensor tendon of the fifth toe in the correct position.

OPERATIVE TECHNIQUE

With the patient under general anaesthesia, the skin is prepared by the usual preoperative surgical technique, and the foot and ankle are exposed with appropriate sterile drapes. An Esmarch bandage is applied, starting with the toes and proceeding proximally to the area just above the malleoli. Four turns of the rubber bandage are made above the ankle to serve as a tourniquet. The remainder of the bandage is removed from the exsanguinated foot, preparatory to surgery.

A curvilinear incision, two inches long, is made over the dorsum of the big-toe joint, damage to the extensor-tendon sheath being carefully avoided. The incision is terminated proximally when the tendon of the abductor hallucis has been exposed. The medial aspect of the capsule is then opened with a linear incision, about one and one-half inches long, which is extended from the proximal phalanx across the joint, through the bursa, and over the exostosis, to the middle of the neck of the first metatarsal. The dorsal and plantar edges or flaps of this capsule are separated by sharp dissection from the exostosis, which is subsequently excised with a thin, sharp osteotome.

Attention is then directed to the space between the head of the first and second metatarsals. Dissection is carried down through the overlying sheath to expose the adductor hallucis tendon. When this sheath has been retracted, the adductor hallucis (oblique and transverse portions) and the flexor hallucis brevis muscles are exposed; together, their tendons are found inserted into the lateral lip of the proximal phalanx. The insertion of the adductor hallucis (Fig. 1) is carefully removed, as much tendon length as possible being taken. This detached tendon is then grasped with an Allis forceps and lifted upward, while sharp dissection is used to separate it from the capsule, the lateral sesamoid, and the lateral head of the flexor hallucis brevis. This dissection should be meticulously performed. A strong tendon, about one-half to three-quarters of an inch long and from one-eighth to three-sixteenths of an inch wide, may be obtained. With the relaxation of the lateral capsule of the joint facilitated by the removal of the adductor hallucis, the hallux valgus can be corrected easily.

The flexor hallucis brevis is permitted to remain attached to the lateral sesamoid bone, which becomes restored to its anatomical position beneath the head of the first metatarsal. The surgeon should be warned here against a possible danger. If all the tendons (adductors and flexor brevis) should be transplanted and no restraining or stabilizing structure allowed to remain on the lateral aspect of the proximal phalanx, the great toe may assume a position of marked varus. The long extensor tendon likewise may shift to the tibial side of the joint and thus create a persistent bowstring effect, contributing further toward maintaining an overcorrected position or varus deformity.

A five-millimeter twist drill is used to make an opening transversely (parallel with

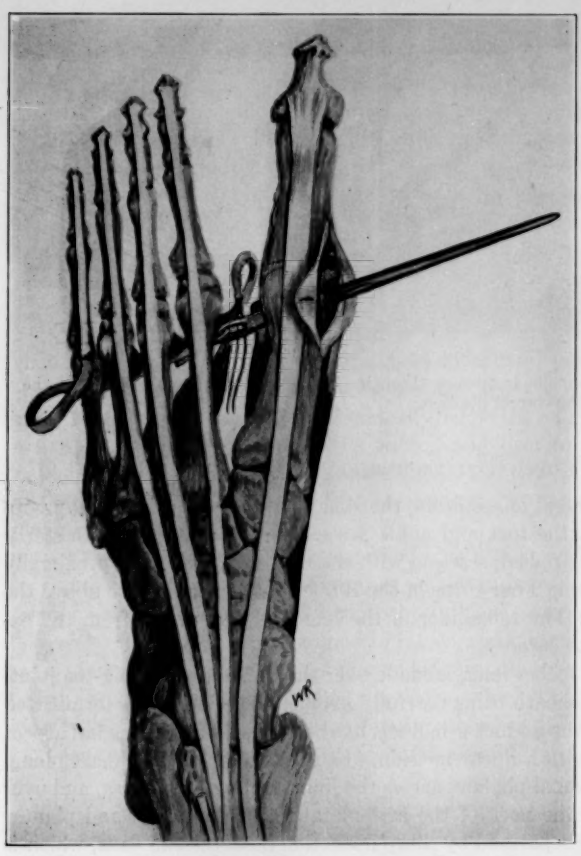

FIG. 4

Both the adductor hallucis tendon and the fifth extensor tendon are inserted through the drill hole.

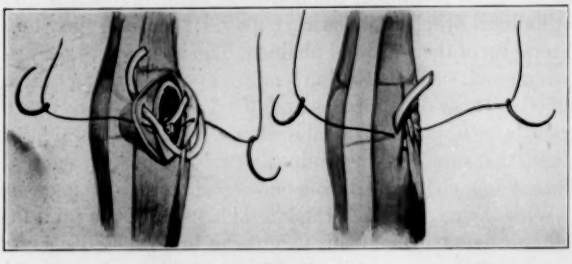

FIG. 5

After the fifth extensor tendon has been passed through the plantar flap of the capsule, distal to the drill hole, it is brought proximally and passed through a slip of the abductor hallucis tendon. Thence it is brought through the dorsal flap of the capsule and drawn tightly to produce a reef in the medial portion of the joint capsule.

the sole of the foot) through the neck of the first metatarsal. The exact location of this opening is determined by holding the tendon of the adductor hallucis up and out of the wound under slight tension. The drill hole is placed at the point where the tendon crosses the neck of the first metatarsal.

Attention is then directed to the opposite side of the foot (Fig. 2). A short curved incision is made over the fifth metatarsophalangeal joint. Dissection is carried down to the capsule, which is incised between the tendons of the abductor digiti quinti and the extensor longus.

The proximal position of the long extensor tendon of the fifth toe is demonstrated by tension placed on its distal portion. A small transverse incision is then made within the natural skin fold at the designated point, just anterior to the ankle. Dissection is carried down to the anterior ligament, which is incised transversely for a short distance, to expose the bundle of extensor tendons. The fifth tendon can be recognized when gentle traction again is applied distally. The foot is then strongly flexed to facilitate removal of as much of the tendon as possible. The severed distal end, when grasped with curved Kelly forceps, may be easily passed down the common tendon sheath, if the curve of the forceps is kept upward to conform to the contour of the foot and ankle. This procedure usually frees the tendon mesentery and enables the operator to draw the tendon through the distal wound without incising the skin throughout its course.

The exostosis over the distal, lateral aspect of the fifth metatarsal is exposed and

excised with a rongeur. Great care is taken to avoid unnecessary exposure of the joint or trauma to the articular cartilage. A towel clip (Fig. 3) is used to make an opening in the cancellous bone, just proximal to the head of the fifth metatarsal. Through this small hole a silk suture is passed to fix the extensor tendon to the raw bone surface, the fifth toe being held in neutral position. The abductor digiti quinti tendon is brought anteriorly and sutured to the long extensor tendon of the fifth toe, over the base of the proximal phalanx, to prevent permanent toe flexion should the transplanted tendon later become stretched. The capsule is carefully replaced.

A small tendon passer is then inserted between the retracted abductor digiti quinti tendon and the shaft of the fifth metatarsal (Fig. 4); it is passed across the sole of the foot, just beneath the necks of the lateral four metatarsals, care being taken to keep within the plane of the transverse head of the adductor hallucis and parallel with its fibers. The towel clip is removed from the edges of the first incision to permit the tendon passer to deliver the extensor tendon across and out, between the first and second metatarsals, where it is left temporarily.

The two ends of a fairly strong (size 2-0) silk suture, firmly attached to the freed tendon of the adductor hallucis, are brought through the previously made drill hole; one end is passed through the dorsal flap of the capsule, the other through the plantar flap. The extensor tendon is likewise passed through the same opening, carried slightly distally, and inserted through the plantar capsule.

A gauze sponge is placed around the fore part of the foot. While its two ends are drawn firmly together to squeeze the metatarsals together and thus correct the splay-foot deformity, a large Kocher clamp fastens the end of the sponge to maintain this position while the tendons are being fastened firmly. To accomplish this fixation, the extensor tendon, which had just previously been passed through the plantar flap of the capsule, slightly distal to the drill hole (Fig. 5), is directed proximally around a slip of the abductor hallucis tendon, up through the dorsal flap, and back toward the proximal phalanx. It is held there under moderate tension while silk sutures, previously placed through the dorsal and plantar flaps of the capsule, are passed through the fifth tendon graft and tied. The amount of capsule on the medial side of the great-toe joint which is allowed to remain following the reefing procedure may affect the degree of motion of the great toe. For example, placing the tendon graft too near the phalanx necessarily restricts movement.

Furthermore, the transplanted adductor tendon should not be pulled at an acute angle, for rubbing against the edges of the drill hole may cause chafing or division. The tendon graft should pass straight through the drill hole into the capsule at such an angle that free motion of the great-toe joint is permitted. The range of motion of the great toe should be observed before the wound is closed.

The tendon graft thus serves

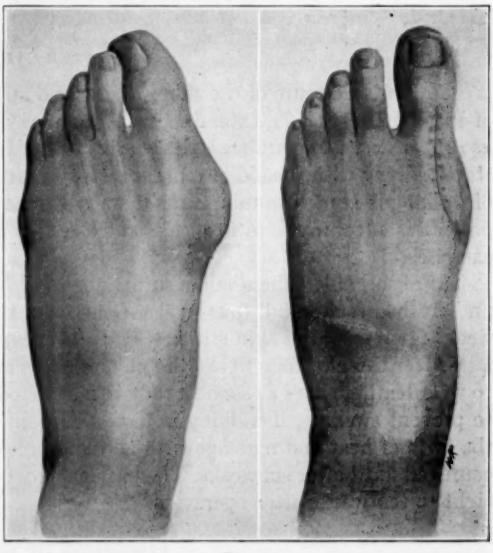

FIG. 6

Comparison of the final appearance of the foot with the view before operation reveals improvement in the functional elements as well as in the cosmetic appearance. The locations of the skin incisions are shown.

three purposes: (1) It approximates the metatarsals, thus correcting the splay-foot and primus varus; (2) it corrects the hallux valgus by abducting the great toe; and (3) it advances the attachment of the abductor hallucis tendon to a position nearer the phalanx by taking a reef in the medial side of the capsule. Thus it repairs the capsule while correcting the deformity.

The gross over-all deformities of the foot are thus corrected,[1] while the function and the configuration are restored to a more nearly normal state (Fig. 6).

FIG. 7

Plaster-of-Paris shoes with rubber heels permit early ambulation.

AFTER-CARE

Following closure of the skin incision and application of dry sterile dressings, plaster-of-Paris shoes (Fig. 7), extending from the toes to above the malleoli, are applied, as well as rubber heels, to permit weight-bearing. After four or five days, the patient is allowed to start walking with the aid of crutches. Hospitalization is no longer necessary. The amount of walking is kept to a minimum as long as standing produces swelling of the toes. The patient is encouraged to keep his feet elevated at all other times and to do toe-curling exercises.

If absorbable subcuticular suture material has been used, the plaster shoes may be undisturbed for the full four weeks. Otherwise, the cast should be split at the end of two weeks for removal of skin stitches, and then reapplied.

After three or four weeks the plaster shoes are removed and the patient is permitted to wear leather shoes as soon as they can be fitted. Compression bandages should be worn to prevent swelling, if walking in loose bedroom slippers is allowed. Physical therapy, in the form of heat and massage with active exercises, is helpful. Standing on tiptoes is discouraged until after six weeks. The patient may expect to resume his usual activities from eight to ten weeks after operation.

DISCUSSION OF FAILURES

Seven patients have had a recurrence of calluses beneath the metatarsal heads. In each case a pre-existing hammer-toe deformity had been allowed to go uncorrected. Where the hammer toe could be passively corrected, division or lengthening of the extensor ten-

don resulted in temporary improvement only, but did not prevent recurrence of the hammer toe with its depressed metatarsal head and plantar callus. Therefore, it appears that hammer-toe deformities should be corrected permanently at the time the sling procedure is carried out.

In a few cases, a certain amount of limitation of flexion and extension of the great toe appeared. Occasionally this caused temporary concern. This limitation necessarily follows the relative tightening of the long flexor and extensor of the great toe, the result of straightening the zigzag line of the original deformity. This limitation of motion may be gradually improved by exercises. The sooner these exercises are started, the more rapidly will a good range of painless motion return to the great-toe joint.

Some degree of sepsis was present in six cases in which silk sutures had been used for closure of the skin. Five of these infections were so-called stitch abscesses. Four cleared readily after removal of a silk suture, and one subsided as a result of bed rest and antibiotics, without removal of the suture. One patient had sensitivity to iodine, previously unknown; sepsis developed postoperatively, but the foot healed completely with an excellent cosmetic and functional result.

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DISCUSSION

Dr. Earl D. McBride, Oklahoma City, Oklahoma: Dr. Joplin has added another step to the multiple surgical procedures for hallux valgus and bunions. The tendon transplantation which he describes should be an excellent procedure for splay-foot. It impresses me as being a bit severe for use in the average patient seeking relief for painful bunions. A minimum of trauma is essential for favorable recovery in operations on a first-toe joint having the usual degenerative changes found in a long-existing bunion deformity. The drilling of holes and the excision or fracturing of bone about the first metatarsal head is an invitation to disappointment.

On the other hand, we do need a procedure for correcting the laxity of the broadened, ungainly splay foot. Dr. Joplin's operation may well prove to be the answer. The metatarsal heads are supported by the intermetatarsal ligaments, together with the transverse portion of the adductor muscle which arises from the plantar metatarsophalangeal ligaments of the third, fourth, and fifth toes. Tightening these structures is desirable in correction of hallux valgus. If the base of the proximal phalanx is removed, as in the Keller operation, the attachments of the adductor structures are permanently lost.

In 1928 and again in 1935, I directed attention to the importance of the adductor hallucis muscle in the correction of hallux valgus. I also stressed that removal of the lateral sesamoid permitted closure of the wide gap between the first and second metatarsal heads.

Subperiosteal fixation of the adductor to the first metatarsal head and firm circumferential sutures to bind the first and second metatarsal heads together takes care of the varus of the first metatarsal. A tendon sling could not bring these two bones any closer together. It should, however, provide a desirable squeezing effect on the metatarsal arch.

Dr. H. Page Mauck, Richmond, Virginia: I was interested in the survey of Dr. Joplin, in which he mentioned the frequency with which the Keller procedure is used at the present time. In our locale, the Keller operation has been reserved for the cases with marked degenerative changes in the joint. We use more conservative procedures, such as the numerous operations described in the 1930's, when it was recognized that the combined action of the adductor and the bowspring action of the extensors and flexors served as a deforming factor.

Dr. Joplin deserves credit for describing an efficient way of attaching the transplanted adductor tendon to the head of the first metatarsal.

(*Continued on page 792*)

THE WELL-LEG-RAISING TEST OF FAJERSZTAJN IN THE DIAGNOSIS OF RUPTURED LUMBAR INTERVERTEBRAL DISC

BY BARNES WOODHALL, M.D., DURHAM, NORTH CAROLINA
AND MAJOR GEORGE J. HAYES, *Medical Corps, United States Army*
From the Neurosurgical Service, the Duke Hospital and Medical School, Durham

A number of so-called sciatic-nerve tension tests have been described to aid in the diagnosis of lesions in the nerve roots forming this major extremity nerve. The most famous of these, the straight-leg-raising test, is credited to Lasègue and bears his name. The eponym is derived from a long dissertation on the subject of sciatica, which Lasègue published in 1864. This paper discussed the clinical course of three patients with sciatica, but did not in any way, as noted by Sjöqvist, include a description of the Lasègue test. This was left to Forst, who dedicated his doctoral thesis upon sciatica to his master, Dr. Lasègue, his mother and father, his teacher, and all of his friends, and who prefaced his remarks by the careful statement that his attention had been drawn to this test or sign of sciatic-nerve involvement by his master.

Forst described the straight-leg-raising test with the aid of two graphic illustrations. The patient lies on the bed in dorsal decubitus. The clinician grasps the heel of the affected extremity with one hand and places the other on the patient's knee. The extended extremity is then flexed on the thigh; in a positive test, pain is produced at the sciatic notch after but a few centimeters of lift (Fig. 1). Forst showed that, if the leg is first flexed on the thigh with care, the thigh may then be flexed on the trunk without production of the characteristic sciatic pain (Fig. 2). Both Lasègue and Forst felt that a positive pain response was due to muscle contraction in the thigh about an involved sciatic-nerve trunk.

De Beurmann again described the straight-leg-raising test in 1884. He, too, pointed out that, if the leg is first flexed on the thigh, no pain will develop when the thigh is subsequently flexed on the abdomen. He questioned the theory that sciatic pain produced by the straight-leg-raising manoeuvre is due to thigh-muscle contraction. De Beurmann demonstrated marked stretch of the sciatic nerve in cadavera during the performance of the Lasègue test, and concluded that this factor of stretch, rather than that of muscle contracture, was the actual cause of pain. This conclusion was restated by Sjöqvist, many years later.

Who first, among the host of writers interested in this subject, described extension of the leg on the thigh following flexion of the thigh on the abdomen, as an obvious variant of Lasègue's sign, cannot be ascertained. Petrén, however, in 1909, stated that a ready method of eliciting sciatic pain is to place the patient in the sitting posture and ask him to extend the knee joint. He drew attention to the similarity between Lasègue's sign and Kernig's manoeuvre in meningitis, and proposed calling the test by their combined names.

Some years before this, Fajersztajn added what he termed a simple and elegant manoeuvre which he thought demonstrated the mechanism of Lasègue's sign. This variation consisted in straight-leg-raising with the leg extended until pain appeared, and then the full production of pain by energetic or gentle dorsiflexion of the foot. He likewise pointed out that, following flexion of the thigh on the abdomen, forceful extension of the leg might elicit a positive response, and that, in severe cases, neck flexion alone was a sufficient stimulus to elicit pain.

In Fajersztajn's paper is found the first mention of the so-called crossed-sciatic phenomenon, or the elicitation of pain in the affected hip and limb by the performance of the straight-leg-raising test on the healthy extremity. Fajersztajn first noticed this finding during physical examinations in 1896, and demonstrated the test to several specialists in 1898. In 1898, he stated, the manoeuvre was mentioned in a cursory fashion

. Nous faisons coucher le malade dans le décubitus dorsal; dans cette position nous prenons d'une main

le pied du membre malade, comme dans la figure n° 1 ; nous plaçons l'autre main libre sur le genou du même membre; ceci fait, en maintenant la jambe dans l'ex-

FIG. 1

jambe sur la cuisse, comme le montre la figure n° 2, nous pouvons fléchir la cuisse sur le bassin, sans faire éprouver au malade aucune sensation douloureuse. Toutefois pour que cette seconde manœuvre réussisse, il faut prendre certaines précautions, qui sont faciles

à comprendre; il faut, disons-nous, fléchir la jambe sur la cuisse, mais pour cela nous agissons lentement, en rasant le talon sur le lit, de façon à ne produire

FIG. 2

Fig. 1: The first manoeuvre of Forst, showing technique of the straight-leg-raising test to elicit sciatic pain. Note flexion of neck, which increases dural-sac tension.

Fig. 2: The second manoeuvre of Forst. This corresponds to Lasègue's original test and does not produce sciatic pain.

by Radzikowski as the sciatic-paradox phenomenon. The technique of the test was carried out with the patient supine. The healthy extremity was flexed forcibly on the thigh with the leg extended, and pain was elicited at 30 to 100 degrees in a positive test. The cross-sciatic sign was considered absent only when this forceful movement was carried out with the additional reinforcement of ankle dorsiflexion. The pain, less severe than in the direct leg-raising test, was described as being in the opposite sciatic notch, from which it might spread into the distribution of the sciatic nerve; it was occasionally noted in the opposite sacro-iliac region. Fajersztajn conducted cadaver dissections to prove his postulate that tension on one sciatic nerve produces tension in the spinal roots of the opposite nerve. With the lumbosacral roots exposed, traction on one sciatic nerve was shown to pull the dural sac caudally and ipsilaterally, and at the same time to displace the contralateral roots in a centrifugal fashion.

In 1907, Moutard-Martin and Parturier, with no apparent knowledge of Fajersztajn's contribution, rediscovered the crossed-sciatic phenomenon, giving to it the name of pain provoked contralaterally.

Several anatomical studies have been made by modern students of this subject, including those of Inman and Saunders, O'Connell [12], Sjöqvist, and Falconer, McGeorge, and Begg. Inman and Saunders pointed out that the change in length of the vertebral canal from full extension to full flexion was a matter of some 7 centimeters. In body flexion, the first and second lumbar nerves showed the greatest excursion, limited to perhaps 2 to 5 millimeters. Lateral flexion of the spine did not produce movement of the contralateral segmental nerves unless the degree was such as to cause tilting of the pelvis and adduction of the contralateral extremity. Cadaver dissection showed evidence of traction upon the sciatic nerves at the fifth lumbar level when the leg was raised 30 degrees from the table; at this point straight-leg-raising caused distal migration of the nerve roots into foramina. The maximum motion (a distance of 2 to 5 millimeters) was obtained at 60 to 80 degrees of flexion in the roots of the fifth lumbar, first and second sacral nerves. In one cadaver examined, this maximum movement amounted to 7 millimeters.

O'Connell mentioned the contralateral leg-raising test, although he did not designate

it as such, but described the carrying out of leg-raising tests in three parts. First, with the patient lying flat, the sound limb is flexed at the hip, extension being maintained at the knee. At times the contralateral pain "is a tightness in the lumbar region or in the posterior thigh of the flexed limb, but frequently flexion of the sound limb produces an exacerbation of the sciatic pain in the opposite limb". The second of his tension tests is the use of the affected leg in leg-raising, and the third test is the use of both legs flexed simultaneously. He pointed out also that "flexion of the neck reduces the degree of straight leg raising which is possible without pain", since flexion of the neck increases tension on the nerve roots of the cauda equina.

From anatomical studies, O'Connell demonstrated that the lumbosacral nerve roots are fixed in their extradural course by two factors,—one, the marked increase in fibrous tissue in their extradural sheaths and, second, the proximity of the fixed attachment of the extradural nerve root at its point of emergence from the dura and another point of fixation farther laterally, where it begins to ramify into its various branches. In the cauda equina the lumbar-sacral nerve roots lie anteriorly, close to the anterior border of the bony canal. By cadaver dissection, O'Connell was able to show that "flexion of both hips with the knees extended produced an obvious increase in tension in both the intradural and extradural roots of both sides, the dura being drawn slightly downwards as well as forwards on to the anterior wall of the spinal canal. The increase in tension was more obvious in the case of the extradural than in that of the intradural roots—a fact due probably to some of the increase in tension on straight leg raising being transmitted to the dura from the extradural roots so that only a proportion of the stretch reached the intradural roots.

"Flexion of one hip only, keeping the knee on this side extended, produced a similar increase of tension in the roots of the corresponding side, and the anterior portion of the dural theca was displaced slightly towards the side of the flexed limb by the movement. Such a movement of the theca towards the flexed limb will produce some increase in tension in the extradural roots of the opposite side, this increase being much less, however, than would result from flexion of the opposite limb itself.

"Further, it was noted that when the extradural roots of one side had been rendered tense by flexing the hip with the knee extended, the tension could be immediately relaxed by flexion of the knee on this side. Finally, it was noticed that flexion of the neck produced an upward movement of both spinal cord and dura within the spinal canal, and, of course, therefore, increased the degree of tension in the nerve-roots coursing downwards from the spinal cord."

Falconer and his associates made observations concerning limitation of straight-leg-raising in sciatica. Disc lesions were exposed with the patient on his side. "As the straight-leg raising test was carried out, the affected nerve root was found to tighten over the summit of the protrusion, in many instances burying itself into the protrusion. It was noted that the distance which the extended leg had to be flexed at the hip before appreciable tension developed within the nerve root corresponded roughly to the degree of limitation of straight-leg raising present before operation. Thus, in cases where this sign had been markedly positive, only a slight degree of flexion at the hip caused the nerve root at the level of the prolapse to be pulled downwards, whereas in cases where this sign was less marked a greater degree of hip flexion could be made before appreciable longitudinal tension developed within the nerve root." If further proof were necessary, these authors pointed out that infiltration of the affected nerve root with a local anaesthetic at the point where it crosses the disc prolapse would relieve pain and would diminish such signs as limitation of straight-leg-raising, indicating that the pain in straight-leg-raising is not due to muscle spasm, but to actual compression and stretch of the extradural spinal roots.

When the straight-leg-raising test was performed on cadavera, it was shown that

"the fifth lumbar and first sacral nerves moved downwards through their respective foramina distances of from 2 to 6 mm., and that this movement did not begin until the leg was flexed about 30° to 40° from the table, and was greatest as the leg was moved from 60° to 90° of flexion. The fourth lumbar nerve moved downwards to a lesser extent, and the remaining lumbar nerves did not move at all." These findings are compatible with those observed by Inman and Saunders. The latter workers postulated the development of some slack or stretch in the extradural nerve root where limitation of straight-leg-raising was slight, as it might be in patients with mild symptoms or in those recovering spontaneously from an acute attack.

There have been but scattered clinical studies of the crossed-leg or well-leg-raising test. Holmes and Sworn presented brief data concerning the "unilateral" and "bilateral" Lasègue sign. Peyton and Simmons analyzed ninety cases of ruptured disc and reported a positive Lasègue sign in 94 per cent. (seventy-five cases) of verified disc lesions. In fourteen cases (17 per cent.), stretching of the sciatic nerve on the healthy side produced pain in the affected extremity. "This observation was not made in any of the cases in which later exploration revealed no lesion." Fincher summarized the findings of the present report in succinct terms by stating: "When straight leg lifting of the opposite extremity exaggerates the sciatic pain of the involved leg one can be doubly certain of a herniated disk". Love mentioned the well-leg-raising test in a discussion of diagnostic tests.

THE MECHANISM OF THE WELL-LEG-RAISING TEST AS DEMONSTRATED BY CADAVER DISSECTION AND AT OPERATION

The protocol of one of five cadaver dissections is sufficient to describe findings that seem to confirm those noted by earlier observers.

A white female, thirty-four years old, tested fourteen hours after death, had minimal rigor which prevented leg-raising above 75 degrees. The dural canal was exposed by removal of the upper half of the sacrum and the laminae of the third, fourth, and fifth lumbar vertebrae. The epidural fat was dissected free to expose clearly the dural canal and nerve roots. In the face-down position, the pelvis was immobilized against the side of the table and the legs were allowed to drop into what corresponded to the straight-leg-raising position. At 15 degrees of depression of one leg, movement was noted in the ipsilateral nerve roots, continuing through an arc of 40 degrees. The shift of the ipsilateral roots was in two directions,—first, a caudal movement with the roots entering their respective foramina and, second, a forward movement, tending to approximate the roots to the anterior wall of the spinal canal. On the contralateral side, the nerve roots emerged from their foramina and shifted toward the opposite side, and, to a lesser extent, tended to approximate the anterior wall of the spinal canal (Fig. 3). The fifth lumbar and first sacral nerve roots participated to a greater degree in both ipsilateral and contralateral movements than did that of the fourth lumbar.

The mechanism of the well-leg-raising test can likewise be demonstrated by a comparison between the clinical findings of various sciatic tension tests and the location of the disc protrusion, demonstrated at operation in individual patients. Two recent examples of this phenomenon are recorded briefly.

Case 1. B. R. (Duke Hospital No. C 81105) was admitted on February 15, 1950, with a typical history and neurological findings of a ruptured intervertebral disc at the fifth lumbar interspace on the right side. Roentgenograms of the lumbosacral spine demonstrated slight narrowing at this interspace. No myelogram appeared indicated. Sciatic-nerve tension tests were as follows:

With the patient supine on a firm bed, the right or affected extremity was flexed on the trunk with the leg extended. Pain in the right hip and to the right of the fifth lumbar interspace developed after 10 degrees of movement; further extension was prevented by patient resistance, as the pain became more severe and began to radiate into the right posterior thigh. When the leg was flexed on the thigh at this degree of thigh flexion, the pain was relieved. Subsequent extension of the leg renewed the pain. If the ankle were dorsiflexed or the neck flexed at this degree of thigh flexion with the leg extended, the pain was increased.

When the left lower extremity was flexed at the thigh with the leg extended at the knee, pain developed at the *left* of the fifth lumbar interspace—that is, back pain—at 15 degrees of elevation; at 30 degrees, pain appeared in the affected extremity, first to the *right* of the fifth lumbar interspace and then extending into the *right* hip and upper thigh. Further elevation was resisted because of increased pain in the *right* thigh.

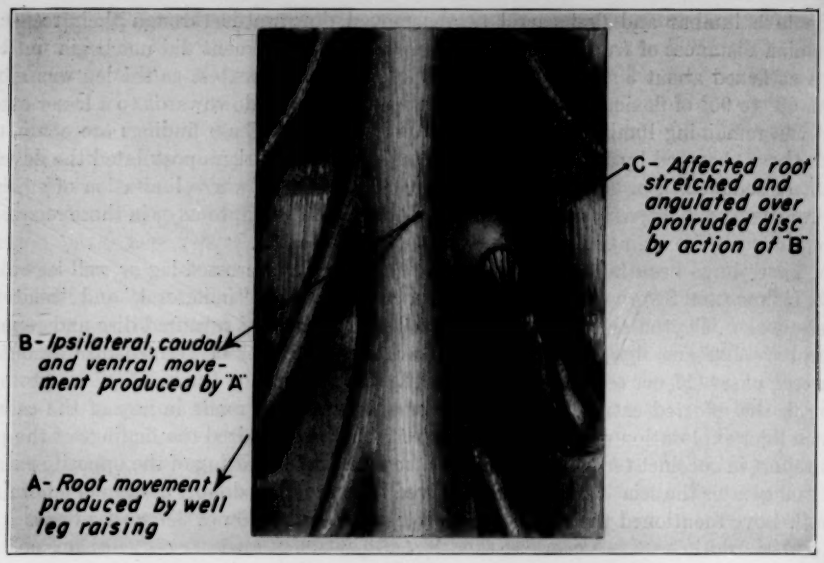
C- Affected root stretched and angulated over protruded disc by action of "B"
B- Ipsilateral, caudal and ventral movement produced by "A"
A- Root movement produced by well leg raising

FIG. 3

Semidiagrammatic illustration of the factors involved in producing pain by the well-leg-raising test. Note particularly the medial relation of the protruded disc to the affected root.

Left ankle dorsiflexion or neck flexion increased the pain reaction in the right lower extremity. When the legs were raised simultaneously, pain was noted in the mid-lumbosacral area and in the *right* hip at 15 to 20 degrees of elevation, and there was a sharp exacerbation of pain as the legs were dropped.

At operation on February 17, hemilaminectomy was done at the fifth lumbar interspace on the right. When the ligamentum flavum had been removed, palpation disclosed a rounded mass projecting from the mid-line of the interspace. There was no protrusion lateral to the first sacral nerve root, but a rounded, irregular mass impinged against the root just below its emergence from the dural envelope. After the first sacral nerve root had been retracted medially over this mass, a massive protrusion was removed through a rent in the posterior longitudinal ligament. The well-leg-raising manoeuvre in this instance tended to stretch the first sacral nerve root of the affected extremity more tautly against and over the protrusion.

CASE 2. E. S. (Duke Hospital No. C 81088) was admitted on February 19, 1950, with severe pain in the right hip and leg and with a history and neurological findings typical of a ruptured intervertebral disc. Standard roentgenograms of the lumbosacral spine in various projections were negative. Sciatic-nerve tension tests demonstrated mid-line lumbosacral pain with acute neck flexion. Dorsiflexion of the left ankle caused no pain; dorsiflexion of the right ankle caused slight mid-lumbosacral pain with slight radiation to the right of the fifth lumbar interspace. Straight-leg-raising on the right or affected side caused sharp pain in the right hip, extending toward the sciatic notch at 15 degrees; when further elevation was attempted, pain developed in the mid-lumbosacral region. Pain in both areas was at once relieved by flexion of the leg on the thigh.

Well-leg-raising (on the *left* side) caused mid-lumbosacral pain at 15 to 20 degrees that rapidly spread to the *right* hip as further elevation was attempted. When both legs were raised simultaneously, *right* hip and back pain developed, similar to that noted with unilateral testing.

A pantopaque myelogram suggested a disc protrusion immediately below and medial to the first sacral nerve root at the fifth lumbar interspace (Fig. 4). On February 21, a hemilaminectomy was done at this interspace. The first sacral nerve root was taut, but no protrusion could be visualized laterally. As the root was retracted medially, a round, well demarcated protrusion was exposed, just beneath and medial to the axillary pouch of this nerve root. The location of the protrusion in respect to the nerve root appears to explain adequately the crossed-leg sciatic test.

DATA SECURED FROM A SURVEY OF PREVIOUS CASES

In order to secure 100 instances of a positive well-leg-raising test, it was found necessary to review the last 304 operations for verified ruptured intervertebral disc carried

out at the Duke Hospital. Among 293 patients, preoperative neurological examinations were performed for a total of 304 operative procedures. In this group, ninety-five patients showed a positive well-leg-raising test in a total of 101 examinations. When the operation records were surveyed, it was found that in ninety-five of the operative procedures a typical protruded disc had been removed. Although some of the operation reports failed to delimit exactly the location of the protrusion, the operator did describe forty-six protrusions through an already ruptured posterior longitudinal ligament, thirty spontaneous protrusions of disc tissue upon incision of the presenting mass, and nineteen "large discs".

FIG. 4

Case 2. In pantopaque myelogram the root sheath of the first sacral nerve on the right is blunted. The density of the opaque column is less on the right side of the sac at the point of protrusion.

Since closer attention has been paid to the location of the protrusion in patients with the positive well-leg-raising test, it has become obvious that protrusions in such patients are never lateral to the involved nerve root, but lie beneath the nerve or medial to it. At the fifth lumbar interspace, the free fragment or protrusion may lie beneath the axillary root of the first sacral nerve or between that root and the dural envelope. In this positive group, there were fifty disc protrusions at the fourth lumbar interspace, forty-four at the fifth lumbar interspace, and two at the third lumbar interspace (one patient with two discs).

Five patients demonstrated a positive well-leg-raising test, and no unequivocal disc lesion was disclosed at operation. Two of these patients had had previous disc explorations and at operation the extradural nerve root was adherent to the spinal canal; one patient had what appeared to be a transverse protrusion which was not treated surgically; in two patients, the operator could demonstrate no pathological lesion at the three caudal interspaces.

SUMMARY

The early history of the Lasègue sign has been reviewed, and credit is given to Fajersztajn for the first demonstration of the crossed or well-leg-raising test. Numerous observers have shown that flexion of the thigh on the abdomen with the leg extended causes rostral movement of the contralateral extradural nerve roots at the fourth and fifth lumbar and first sacral levels, with approximation of these nerve roots to the anterior spine wall; these findings have been confirmed. It has been shown that approximately one-third of all patients with verified disc protrusions have a positive well-leg-raising test, and that almost all of these have large protrusions. In the cases in which this relationship has been studied, the disc protrusion has been found on the medial aspect of the affected nerve root.

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DISCUSSION

Correction of Splay-Foot, Metatarsus Primus Varus, and Hallux Valgus

(*Continued from page 785*)

In regard to the transplantation of the long tendon of the little toe, I am glad he said it was for temporary fixation, approximating the heads of the two metatarsals. Hohmann[1] described, in 1934, a procedure in which a strip of fascia was passed around the base of the head of the fifth metatarsal, carried across, under the heads of the metatarsals, and fixed to the head of the first metatarsal. We have had only three or four cases in which we have used this procedure, but have had a chance to follow them up, and certainly this has been only a temporary fixation. I hope that the adductor muscle will prove more efficient than the fascia.

In regard to the after-care, I feel that, in any case in which an operation has been done for hallux valgus or for splay-foot, some type of support is necessary. The pes planus and valgus heel are factors in these deformities which must be taken into consideration in preventing recurrence.

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SYMPATHETIC GANGLIONECTOMY AND LIMB LENGTH IN POLIOMYELITIS *†

BY JOSEPH S. BARR, M.D., ALLAN J. STINCHFIELD, M.D., AND JOHN A. REIDY, M.D., BOSTON, MASSACHUSETTS

From the Department of Orthopaedic Surgery, Massachusetts General Hospital, Boston

There is good clinical evidence that the circulation in a short extremity, weakened by poliomyelitis, is decreased as compared with that in the normal or less involved limb. This contrasts with observations relative to unilateral hypertrophy and increase in length, associated with conditions such as chronic infections, tumors, and fractures, in which the blood flow is increased. It would seem logical, therefore, to expect stimulation of growth if an increase in circulation could be established in a weak, short limb. We know from investigations on the sympathetic nervous system that interruption of the sympathetic pathways to the lower extremities brings about a definite increase in blood flow to the extremity.** We would thus expect lumbar ganglionectomy to stimulate growth in the shorter limb of a child with poliomyelitis, and to have a tendency to diminish or correct any existing inequality in limb length.

Animal experimentation has failed to confirm the belief that lumbar sympathectomy will stimulate growth of the lower extremity. Cannon, after performing unilateral ganglionectomy in young kittens, stated that there was no demonstrable difference between the two sides and concluded that the sympathetic system is not concerned with growth of the skeleton. Harris and McDonald's experiments on animals confirmed Cannon's findings. Ten kittens failed postoperatively to get increased growth in the extremity. Twelve puppies on which left lumbar ganglionectomies had been done showed no clear-cut evidence of increased circulation or change in the rate of growth. Similar operations on eight lambs also failed to cause increased growth of the extremities. The same conclusion was reached by Bacq, studying the hind limbs of albino rats; Bisgard, studying the limbs of goats; and Simon, working with the forelimbs of rabbits.

Harris, in 1930, argued: "There are certain aspects of the problem which do not lend themselves to animal experimentation. Chief of these is the question whether destruction of the anterior horn cells in the lower dorsal and lumbar segments of the cord by the virus of anterior poliomyelitis does not also result in destruction of, or damage to, the closely related cells which give rise to the sympathetic outflow." It seemed that an answer to this question could be obtained only by operating upon a suitable patient. Harris reported a case in which an increased rate of growth followed unilateral lumbar ganglionectomy. He also reported a case in which left lumbar ganglionectomy was done for Hirschsprung's disease; in this instance, too, there was an increased rate of growth in the lower extremity.

Ogilvie noted that the early postoperative results were uniformly favorable following ganglionectomy in four cases of poliomyelitis. The circulation improved markedly, and one patient had the desired increase in rate of growth of the extremity.

Harris and McDonald, in 1936, reviewed the results of forty-six lumbar ganglionectomies in children. The average age at the time of operation was 8.5 years; the cases were reviewed from one to seven years after operation. In twenty-one cases (46 per cent.) the discrepancy in limb length became less, in amounts varying from one-eighth of an inch to one inch. In eight of the cases, the discrepancy remained unchanged. In seventeen, the discrepancy progressed in spite of the operation. Where the discrepancy

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** This increase is measured under basal conditions and is mainly cutaneous, our knowledge of the response in muscle and bone being incomplete at this time.

increased, a high percentage of limbs failed to retain the increased warmth and vascularity, whereas the opposite was true in the successful cases. Harris and McDonald advised that the operation be done as early as the age of six.

Peabody and Graham, in 1937, reported that they had watched their early poliomyelitis cases for vasomotor changes and shortening, as they felt that shortening was closely related to peripheral circulatory disturbances. They performed ganglionectomies on sixteen patients in the period from 1931 to 1937. In all of these there was a good vasomotor response, and all but three showed "complete cessation of the progressing difference".

The authors have analyzed the results of unilateral lumbar ganglionectomy in twenty-three children with poliomyelitis. The operations were carried out either at the Massachusetts General Hospital or The Newington Home and Hospital for Crippled Children, according to the technique described by White and Smithwick. In practically every instance the lumbar ganglia with connecting rami from the first to the third lumbar vertebrae, inclusive, were removed. End-result data were tabulated in an effort to determine whether stimulation of growth had occurred in the treated shorter extremity. It is obviously difficult to assess the effect of ganglionectomy upon growth of the lower extremity. Previous studies by Stinchfield, Reidy, and Barr show that there are marked individual variations in limb-length discrepancies, but there is a definite correlation between the relative muscle power in the two extremities and the final limb length in children who contracted poliomyelitis before the age of eleven. It seemed advisable, therefore, to compare the sympathectomy cases with a control group showing similar muscle involvement. In the present state of our knowledge, this seems to be the best method for determining the effect of sympathectomy on limb length.

Selection of Cases for Sympathectomy

This series includes all cases treated at the Massachusetts General Hospital and at The Newington Home and Hospital for Crippled Children in which a sufficient length of time has elapsed to permit end-result study. The cases were selected for sympathectomy primarily because of an obvious discrepancy in limb length. A control series of cases not subjected to ganglionectomy were studied in an identical manner, and the results were compared with the operative cases.

In each group there were thirteen males and ten females. The age at onset of poliomyelitis in the ganglionectomized group varied from nine months to seven years and nine months, and in the control group from two months to six and one-half years. The average age at onset for the surgically treated group was one and one-half years; for the control group, two years and ten months. Five of the sympathectomized cases required subsequent operative procedures to equalize limb length and, therefore, end results at maturity could not be obtained. However, the shortest follow-up was four years and five months, which gave adequate time to evaluate the effects of the lumbar sympathetic ganglionectomy on growth.

The amount of muscle power in the lower extremities of patients in both groups was compared by the method described previously by Stinchfield, Reidy, and Barr. This is as follows: Twenty-three muscles or muscle groups in each leg, rated N, G, F, P, T, or 0 by the Lovett method of muscle testing, are given numerical ratings of 5, 4, 3, 2, 1, and 0, respectively, and the totals for each extremity are found. The score for an entirely normal extremity is 115; for a completely flail limb, 0. In these two series of cases, the average score for the stronger extremity in the sympathectomized group was 108; in the controls it was 105.9. The weaker extremity in the operative cases had an average score of 53; in the controls, 61.2. There was, therefore, very little difference in the average amount of paralysis in the lower extremities in these two groups.

Alterations of the discrepancy in length between the two limbs were carefully observed. All but three had clinical measurements from the anterior superior spine to the

medial malleolus, and most of them had roentgenographic measurements. The data are given for the sympathectomized cases (Table I) and for the controls (Table II).

The final clinical discrepancy in the ganglionectomized cases varied from an increase of 3.6 centimeters to a decrease of 3.2 centimeters. This 3.2-centimeter decrease or evidence of stimulation of growth is apparent in the preoperative and postoperative photographs of patient No. 17901 (P.B.) (Figs. 1-A and 1-B). In the remainder of this presentation, when decrease in discrepancy is mentioned, it is to be considered a stimulating effect on growth.

The summary of Case 17901 (P.B.) is as follows:

1931 Year of birth.
1933 Patient contracted poliomyelitis. Treated by local doctor.
Patient referred to Massachusetts General Hospital. Left lower extremity flail; right, fair to good. Total muscle score: left 14, right 66.
1937 Erector spinae transplant, left.
1939 Arthrodesis of foot and posterior transplant, right.
1941 Lumbar sympathetic ganglionectomy, left.
1947 Walks with crutches and long brace on left lower extremity when out of doors. Crutches not used indoors.

In this case (Chart I) the skin temperatures indicated a persistent partial vasomotor denervation of the left lower extremity, six years after lumbar sympathetic ganglionectomy. This persistence of vasomotor response was not present in every case (Table I).

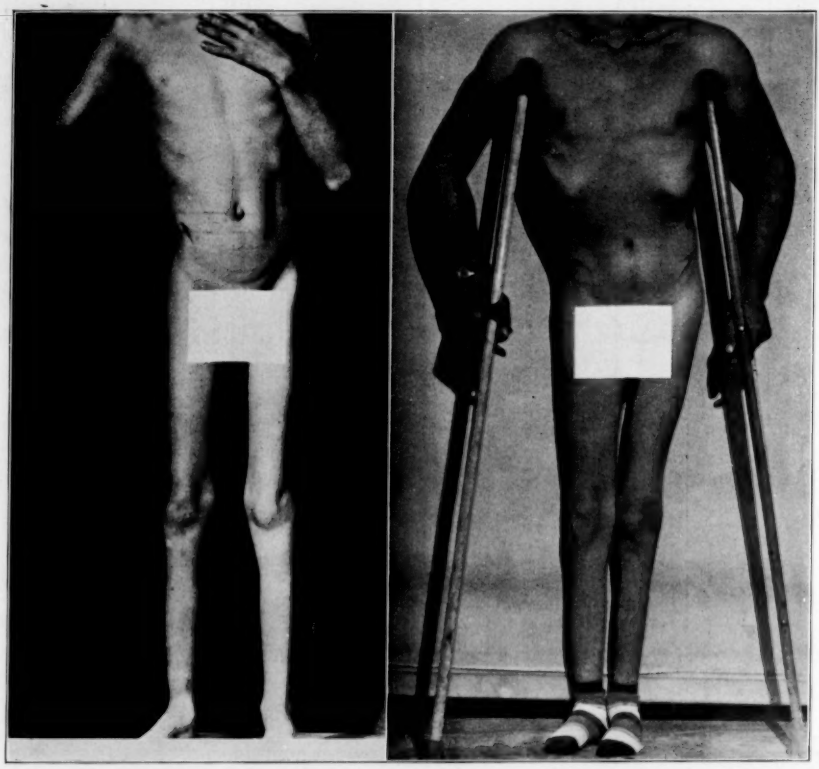

FIG. 1-A FIG. 1-B

Fig. 1-A: P.B. Photograph taken on June 30, 1941, before left lumbar sympathectomy was carried out.
Fig. 1-B: Photograph of September 6, 1949, eight years after sympathectomy.

TABLE I

SYMPATHECTOMY CASES

Case	Sex	Age at Onset	Muscle Power R/L	Age at Operation / Last Exam. (Yrs.—Mos.)	Discrepancy (centimeters) Preoperative Last Exam. Clinical	Preoperative Last Exam. X-Ray	Increase Clinical	Increase X-Ray	Decrease Clinical	Decrease X-Ray	Vasomotor Response Preoperative	Vasomotor Response End Result
1				8— 2	6.1	7.9						
C.H.	M.	9 mos.	35/115	17— 0	8.4	8.9	2.3	1.0			0	+
2				8— 6		5.8						
J.M.	F.	1 yr.	115/57	17— 6	*	7.1	1.3	1.3			0	++
3				10— 4	5.8*	5.8						
O.G.	F.	2 yrs.	32/107	17—11	8.9	7.9	3.1	2.1			0	?
4		2 yrs.		10— 7	5.8	5.3						
V.D.	F.	7 mos.	30/115	19— 0	7.6	7.1	1.8	1.8			0	0
5				10— 9	2.5	3.6						
J.D.	M.	2 yrs.	71/115	18—10	3.8	2.8	1.3			0.8	0	++
6		2 yrs.		11— 1	2.5	2.5						
F.G.	F.	11 mos.	30/90	18—10	2.3	1.8			0.2	0.7	0	?
7		1 yr.		8— 8	2.3	2.0						
M.G.	M.	11 mos.	78/90	17— 2	0	2.0			2.3	0	0	+
8				9— 9	5.1	3.1						
F.R.	M.	2 yrs.	98/15	18— 1	5.1	3.6	0	0.5			0	++
9		7 yrs.		11— 5	3.1	3.8						
A.M.	F.	6 mos.	53/115	19— 9	5.1	4.6	2.0	0.8			0	±
10				8— 1	1.3	1.5						
S.S.	F.	1 yr.	115/73	12— 6	4.1*	4.1	2.8	2.6			0	0
11				11—11	5.1	6.4						
A.S.	M.	2 yrs.	115/44	20— 9	2.3	3.6			2.8	2.8	0	?
12		3 yrs.		9— 2	3.2	7.4						
D.J.	F.	3 mos.	115/32	18— 9	0.6	2.3			2.6	5.1	0	+
13				9— 2	1.8	2.5						
P.P.	M.	1 yr.	115/53	16— 9	2.0	2.5	0.2			0	0	±
14				8— 2	2.5	2.5						
R.E.	M.	1 yr.	88/115	17— 5	1.3	2.3			1.2	0.2	0	++
15				10— 6	2.5	1.3						
P.B.	M.	2 yrs.	66/14	17— 0	-0.7	-0.5			3.2	1.8	0	++
16				11— 0	2.0	1.3						
A.E.	M.	4 yrs.	73/111	17— 2	1.3	1.0			0.7	0.3	0	±
17				6—10	1.0	0.4						
F.M.	M.	1 yr.	66/115	15— 7	1.3	1.5	0.3	1.1			0	++
18				6— 2	1.5	2.3						
J.Z.	M.	2 yrs.	115/69	13—11	1.9	2.8	0.4	0.5			0	?
19				4— 8	2.5	1.0						
L.R.	M.	1 yr.	115/83	13— 0	2.3	1.8		0.8	0.2		0	++
20		4 yrs.		7— 6	0.5							
D.H.	F.	8 mos.	92/115	13— 0	2.5		2.0				0	++
21				6— 1	2.5							
E.D.	F.	1 yr.	83/17	11— 5	3.3	4.3	0.8				0	++
22				5—11	2.8	1.8						
R.B.	M.	2 yrs.	115/43	11— 8	6.4		3.6				0	?
23				7—11	5.1							
R.C.	F.	1 yr.	69/115	12— 4	4.6				0.5		0	0

* X-ray measurements used; clinical measurements not available.
? = No data.
0 = Extremity colder than one not operated upon.
+ = Affected extremity slightly warmer than one not operated upon.
± = Same temperature in two extremities.
++ = Affected extremity definitely warmer than one not operated upon.

TABLE II

CONTROLS

Case	Sex	Age at Onset	Muscle Power R/L	Age at First Exam. / Last Exam. (Yrs.—Mos.)	Discrepancy (centimeters) First Exam. / Last Exam. Clinical	X-Ray	Increase Clinical	X-Ray	Decrease Clinical	X-Ray
1				12— 0	0.8					
A.C.	F.	5 yrs.	71/115	19— 9	1.3		0.5			
2				8— 3	1.5					
E.McN.	M.	6 yrs.	72/115	38	2.5	2.8	1.0			
3		3 yrs.		4— 5	0					
D.P.	F.	6 mos.	115/86	24— 1	2.5		2.5			
4				12— 1	1.3					
F.S.	M.	5 yrs.	115/69	20— 1	2.5		1.2			
5				6— 6	4.6					
I.S.	F.	9 mos.	46/115	18— 8	6.4		1.8			
6		1 yr.		7— 9	1.3					
S.C.	M.	6 mos.	100/65	18— 5	2.3		1.0			
7				11— 5	2.3					
D.D.	F.	7 yrs.	103/26	26— 1	6.4	6.1	4.1			
8				9— 4	0					
W.McD.	M.	9 mos.	68/7	17—10	1.5	1.3	1.5			
9				9— 0	2.0					
H.R.	M.	3 mos.	25/103	17— 4	3.3		1.3			
10				12— 0	2.5					
A.S.	M.	1 yr.	37/71	39	5.1	2.3	2.6			
11		2 yrs.		7— 9	0.8	1.0				
M.W.	F.	9 mos.	115/97	13— 0	0	1.3		0.3	0.8	
12				9— 5	0					
E.L.	F.	5 yrs.	44/5	24— 0	1.3	4.1	1.3			
13				11— 5	1.3					
J.F.	M.	2 mos.	115/77	21— 0	2.3	1.8	1.0			
14				7—10	1.3					
W.C.	M.	5 yrs.	115/21	18— 9	5.8		4.5			
15				4—11	0.8					
R.H.	M.	3 yrs.	115/60	17— 4	2.0	1.5	1.2			
16				6—11	1.3					
J.H.	M.	1 yr.	92/114	16—10	3.3	2.5	2.0			
17				5— 8	1.3					
C.DeA.	F.	1 yr.	100/115	17— 9	2.8	2.5	1.5			
18		6 yrs.		8— 9	0					
E.G.	F.	6 mos.	100/115	14— 7	2.3	1.0	2.3			
19				10— 1	1.3					
F.C.	F.	3 yrs.	76/115	27— 6	2.0	0.8	0.7			
20				12— 0	5.1					
E.N.	F.	4 yrs.	115/32	23— 3	6.4		1.3			
21				8— 0	0.8					
A.B.	M.	2 yrs.	91/115	14— 9	2.3		1.5			
				14— 0		2.0				
22				7— 0	0.8					
J.J.F.	M.	6 yrs.	115/72	30— 0	7.9		7.1			
23				10— 2	2.0					
B.E.	M.	1 yr.	71/114	20— 8	1.3				0.7	

Nine patients showed definite evidence of vasomotor denervation; three showed some evidence; three showed slight evidence; and three showed no indication of denervation at follow-up examination. Five had inadequate examinations. In the nine cases with a

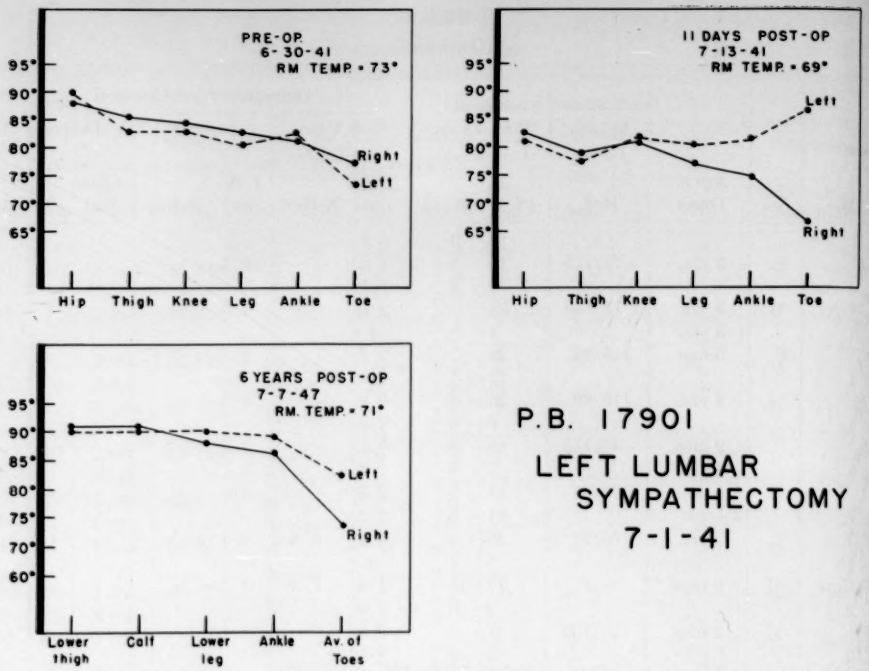

CHART I

Skin temperature in P.B., before and after left lumbar sympathectomy.

marked lasting vasomotor response, the average increase in discrepancy in limb length at end-result study was 0.12 centimeter. The nine cases with little or no lasting vasomotor response showed an average increase in discrepancy of 0.33 centimeter. This shows that the degree of stimulation had very little correlation with lasting vasomotor response.

The clinical discrepancy in limb length in the surgically treated cases increased in thirteen instances (57 per cent.); in the controls the discrepancy increased in twenty-one (91 per cent.). The clinical discrepancy was decreased in nine cases in the sympathectomized group, and in only two of the control group. By clinical measurement, the total increase in discrepancy in thirteen cases (Table III) was 21.7 centimeters; the total de-

TABLE III

DISCREPANCY IN LIMB LENGTH *

		Total (*Centimeters*)	Average Increase (*Centimeters*)
Controls (23 cases)	21 Increased	41.9	1.8
	2 Decreased	1.5	
Ganglionectomy (23 cases)	13 Increased	21.7	0.3
	9 Decreased	13.7	
	1 Unchanged		
Calculated average decrease in discrepancy due to ganglionectomy			1.5

* This was based on a clinical measurement from the anterior superior spine to the medial malleolus except in three cases, in which x-ray measurements were used.

TABLE IV

ANALYSIS OF DATA

Case	Sex	Muscle Power R/L	Discrepancy at Operation* (*Centimeters*)	Predicted Final Discrepancy Without Operation (*Centimeters*)	Final Discrepancy (*Centimeters*)
1 C. H.	M.	35/115	6.1	5.8	8.4
2 J. M.	F.	115/57	5.8	4.0	7.1
3 O. G.	F.	32/107	5.8	4.5	8.9
4 V. D.	F.	30/115	5.8	6.4	7.6
5 J. D.	M.	71/115	2.5	2.3	3.8
6 F. G.	M.	30/90	2.5	4.8	2.3
7 M. G.	M.	78/90	2.3	0.5	0.0
8 F. R.	M.	98/15	5.1	5.5	5.1
9 A. M.	F.	53/115	3.1	4.0	5.1
10 S. S.	F.	115/73	1.3	2.3	4.1
11 A. S.	M.	115/44	5.1	5.8	2.3
12 D. J.	F.	115/32	3.2	5.8	0.6
13 P. P.	M.	115/53	1.8	4.0	2.0
14 R. E.	M.	88/115	2.5	2.3	1.3
15 P. B.	M.	66/14	2.5	2.9	−0.7
16 A. E.	M.	73/111	2.0	2.3	1.3
17 F. M.	M.	66/115	1.0	4.0	1.3
18 J. Z.	M.	115/69	1.5	4.0	1.9
19 L. R.	M.	115/83	2.5	2.3	2.3
20 D. H.	F.	92/115	0.5	1.2	2.5
21 E. D.	F.	83/17	2.5	4.8	3.3
22 R. B.	M.	115/43	2.8	5.8	6.4
23 R. C.	F.	69/115	5.1	4.0	4.6
Total			73.3	89.3	81.5
Average			3.2	3.9	3.5

* All measurements are clinical except in Cases 2, 3, and 10, where x-ray measurements were used.

crease, 13.7 centimeters. One case showed no change in discrepancy. Therefore, the overall increase in discrepancy was 8.0 centimeters for the twenty-three cases, or an average

increase of 0.3 centimeter in the group having ganglionectomy. The control group, however, had a total increase in discrepancy of 41.9 centimeters and only 1.5 centimeters decrease, giving an increase in discrepancy of 40.4 centimeters, an average of 1.8 centimeters per case.

Comparing the 0.3-centimeter average increase in discrepancy in the ganglionectomized group with the increase of 1.8 centimeters in the control group, we see that sympathectomy has apparently effected a stimulation of growth in the shorter extremity of approximately 1.5 centimeters per case.

If the roentgenographic measurements in the cases in which the operation was performed are compared with the clinical measurements of the controls (roentgenograms of all of the controls were not available), they show apparently an even greater over-all improvement. There was an average increase in discrepancy of 0.04 centimeter (in nineteen cases) in the ganglionectomized series, compared with the average clinical increase of 1.8 centimeters for the controls, indicating an average stimulation of approximately 1.8 centimeters from the lumbar ganglionectomy.

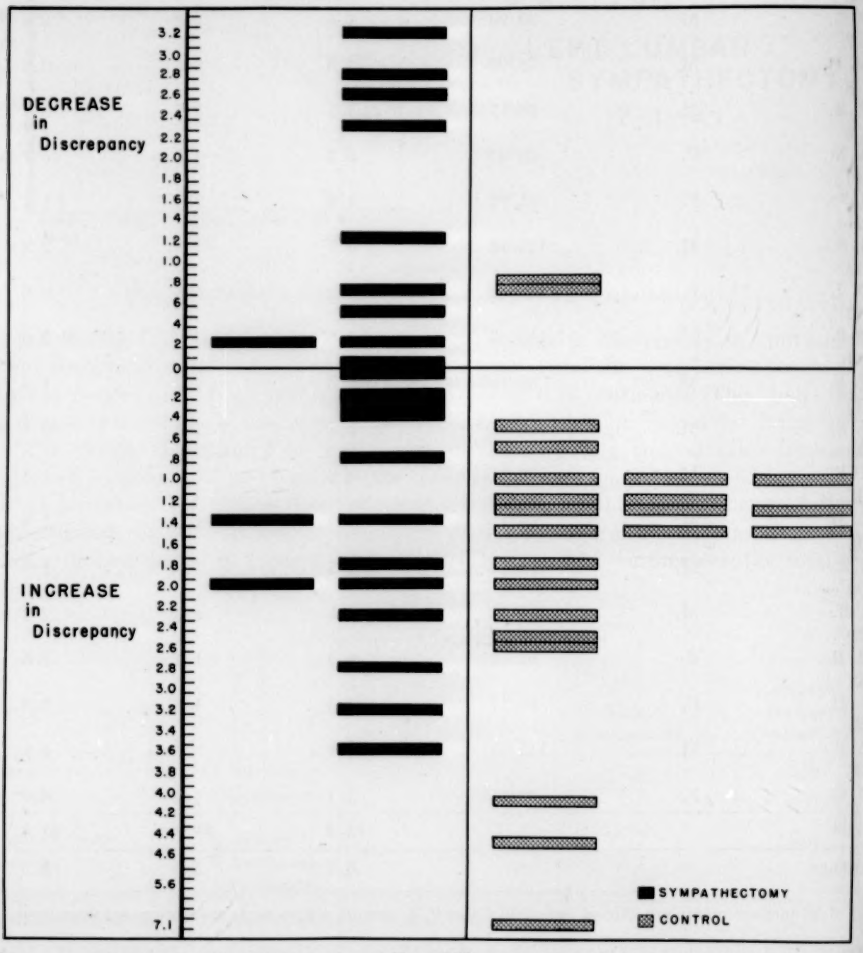

CHART II

Increase and decrease in discrepancy in sympathectomized and control cases.

Further analysis of the data, employing our chart for growth prediction, which is based upon the muscle-power score in the two extremities, is shown in Table IV. The average preoperative discrepancy was 3.2 centimeters, the final discrepancy was 3.5 centimeters, and the predicted discrepancy was 3.9 centimeters. The average discrepancy continued to increase despite lumbar ganglionectomy, but the final discrepancy was 0.4 centimeter less than the predicted discrepancy. This decrease in the expected amount of average discrepancy appears to be due to the stimulating effect of lumbar ganglionectomy upon growth of the shorter extremity.

DISCUSSION

Review of the literature and the authors' own analysis suggest that ipsilateral lumbar ganglionectomy has, in some instances, a stimulating effect upon the growth of the shorter extremity of a patient with poliomyelitis. In the thirteen patients who showed an increase in discrepancy following operation, the discrepancy averaged 1.7 centimeters, compared with 2.0 centimeters in the controls. This is an interesting correlation which suggests that, in these thirteen cases, the ganglionectomy had no particular effect on longitudinal growth (Chart II). The fact that the discrepancies decreased in nine patients operated upon and in only two controls suggests that the former group had effective ganglionectomies. This stimulation is probably the result of the increased blood flow which occurs after ganglionectomy.

However, in this group of cases there was no definite correlation between elevation of skin temperature and increase in growth. These studies indicate that less than half of the patients treated by lumbar ganglionectomy had a definite decrease in their limb-length discrepancy. By comparing with a control group, the authors have been able to show that the patients had an average decrease in discrepancy of 1.5 centimeters; by another method, utilizing our chart for prediction of growth in paralyzed lower extremities, we have found that the discrepancy in this group decreased an average of 0.4 centimeter.

As a rule, limb-length inequality of 2 centimeters or more is clinically significant, and the use of a corrective lift on the shoe is required. Of the twenty-three sympathectomy cases, seventeen had a final inequality of 2 centimeters or more. Eighteen of the control group had a final inequality of 2 centimeters or more.

The authors feel that lumbar sympathetic ganglionectomy can be used in the treatment of minor discrepancies in limb length, but is probably best supplemented or supplanted by other methods, if the discrepancy is of any magnitude.

NOTE: The sympathectomies on these patients were done by James C. White, M.D., and Reginald H. Smithwick, M.D., of Boston, and Ashley W. Oughterson, M.D., of New Haven. Twelve of the twenty-three cases are from The Newington Home and Hospital for Crippled Children, Hartford, Connecticut. The cooperation of the operating surgeons in permitting the authors to study these cases and of Maurice M. Pike, M.D., and Bernard J. Hubenet, M.D., in collecting end-result data on the Newington cases is gratefully acknowledged.

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DISCUSSION

DR. ROBERT I. HARRIS, TORONTO, CANADA: There is ample evidence that increase in the circulation of an extremity which is still growing enhances its rate of growth. Perhaps the most striking evidence of this is found in those cases of arteriovenous aneurysm which occur in children. Traumatic arteriovenous aneurysm or multiple congenital arteriovenous communications (diffuse hemangioma of one lower extremity) cause greater growth in the involved than in the normal extremity.

We have had an opportunity also to examine children who, at the age of two to four years, had left-sided lumbar sympathectomy performed for the treatment of Hirschsprung's disease. In each of three cases there was over growth of the left lower extremity by three-quarters of an inch to an inch.

Many other conditions which are associated with prolonged increase in circulation in the vicinity of the distal femoral and proximal tibial epiphyses will give rise to enhancement of growth of the involved extremity. Examples of such conditions are synovial tuberculosis of the knee, long-continued inflammatory reaction in the region of the knee from any cause, fracture of the femur, and tumors near epiphyseal lines.

Our first paper, published in *The Journal* in October 1930, recorded these observations, together with the result of lumbar sympathectomy in one case in which shortening of the lower extremity was due to poliomyelitis. The shortening was reduced from one and one-half inches to one-half inch. Not only had the progressive shortening been halted, but the enhancement of the rate of growth was sufficient so that one inch of length was regained for the short lower extremity.

Our experience with sympathectomy in the treatment of the short limb of poliomyelitis was recorded by J. L. McDonald and myself in *The Journal* in January 1936. Generally speaking, an adequate sympathectomy can be counted upon to produce a persistent increase in the circulation and to maintain it indefinitely. The effect upon growth is less uniform and sure, and certain reasons for this are obvious. The duration of the effect of enhancement of circulation upon growth varies greatly from patient to patient. It depends upon the time of operation prior to epiphyseal closure and upon the amount of growth which takes place during this period. There may be other factors. It was possible to state from a review of our cases that, when a good increase in circulation had been obtained and maintained, evidence of some enhancement of growth was found in about three quarters of the cases. In 20 per cent. this enhancement of growth was sufficient to result in significant diminution of the shortening.

It is of great interest to hear of the work of Dr. Barr and his associates, and to listen to Dr. Reidy's presentation. We hope they will continue their study, because it has a place in the treatment of the lower extremity paralyzed by poliomyelitis.

DR. CHARLES W. PEABODY, DETROIT, MICHIGAN: Although there is much that could be discussed, I shall confine myself to general considerations based on experience.

A good many aspects of this disease remain for me as speculative and mysterious as ever. One of these has been the correlation of loss of growth in an affected limb with other residual factors. Correlation has been observed, in general, between the factors of disuse and the degree of flaccidity, on the one hand, and the factor of retardation of growth, on the other hand. Quite frequently, however, there have been encountered situations of nearly complete paralysis of one lower extremity, yet minimal difference in length; on the other hand, instances of minimal paralysis were found with notable discrepancy in growth.

About twenty years ago I became impressed, in a northern United States latitude, with the incidence among paralytics of chilblains in severe winter weather, and of difficulty in preventing discomfort from cold in the affected limbs. In the main, those were the cases in which growth was being most significantly retarded. All such patients presented a markedly cyanotic, cold, and clammy extremity on the cold days, which was sufficiently in contrast, in degree at least, with that of patients in whom retardation of growth was minimal, to seem significant.

Soon after those observations, my attention was called to a report by Robert Harris of growth acceleration following lumbar ramisection. As a result, in subsequent years about a dozen small children, who a few years after paralysis were observed to be losing length at an ominous rate and with notable surface temperature change, were treated by lumbar ganglionectomy.

The immediate results were most impressive in that the affected side became at once warmer and had better color than the normal. This effect persisted only for the first year or two, but in no case did the situation revert to prior circulatory status. A few of these children had from one-fourth to one-half an inch in reduction of discrepancy, but that was the maximum obtained.

On the other hand, the previous discrepancy in limb length became static in most of the remainder. For

(*Continued on page 814*)

LONGITUDINAL GROWTH OF THE HUMAN VERTEBRA

A Contribution to Human Osteogeny *

BY EDGAR M. BICK, M.D., AND JOSEPH W. COPEL, M.D., NEW YORK, N. Y.

WITH THE TECHNICAL ASSISTANCE OF MRS. SARAH SPECTOR

From the Orthopaedic Service, Mount Sinai Hospital, New York City

Many articles have been published concerning the development and growth of the human spine. One needs only to consult the classic writings of Gegenbauer, Bardeen, Schmorl, Junghanns, Gadow, Romer, and Schultz or any of a number of recent papers [4–6, 9, 12, 14, 22] to realize the extent to which the vertebral column has been studied. In the course of the authors' bibliographical search, however, it became apparent that the problem of longitudinal growth of the vertebral body in the human was still a matter of controversy.

The controversy dates from the work of Schmorl, Mau, Junghanns, Scheuermann, and their contemporaries. Schmorl had demonstrated to his own satisfaction that longi-

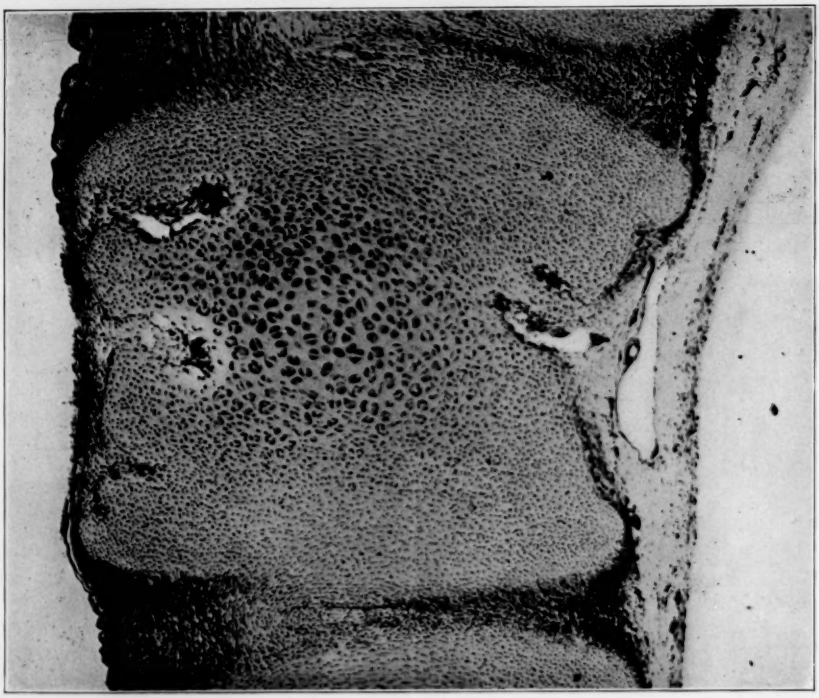

FIG. 1

Photomicrograph (× 40) of specimen from 8-centimeter foetus, aged about fourteen weeks. Cartilage cells are shown developing in the central area of the mesenchyme which, at this stage, forms the body of the vertebra. This is the introductory phase of osteogenesis, and occurs after the provertebral elements have been reformed into the structure which will become the mature vertebral body.

* Based on material exhibited at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York City, February 11 to 16, 1950. Paper read before the Orthopaedic Section, New York Academy of Medicine, March 17, 1950.

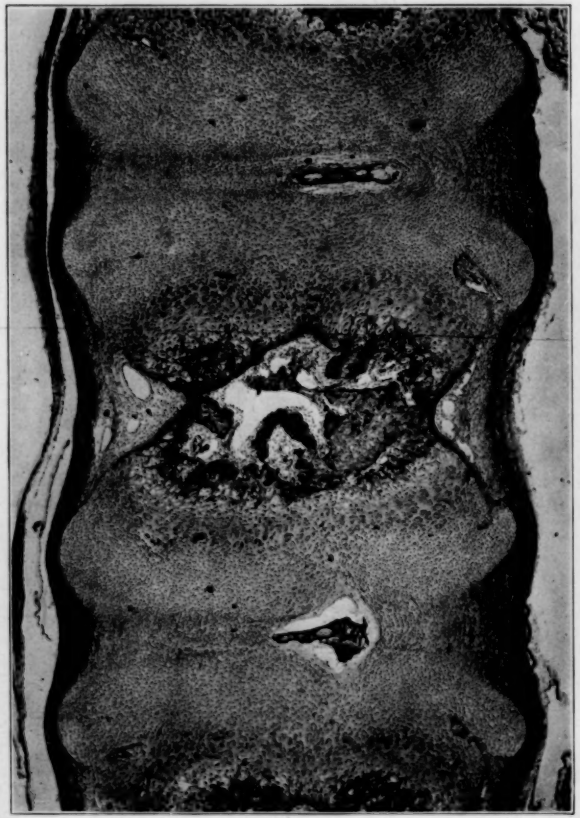

FIG. 2

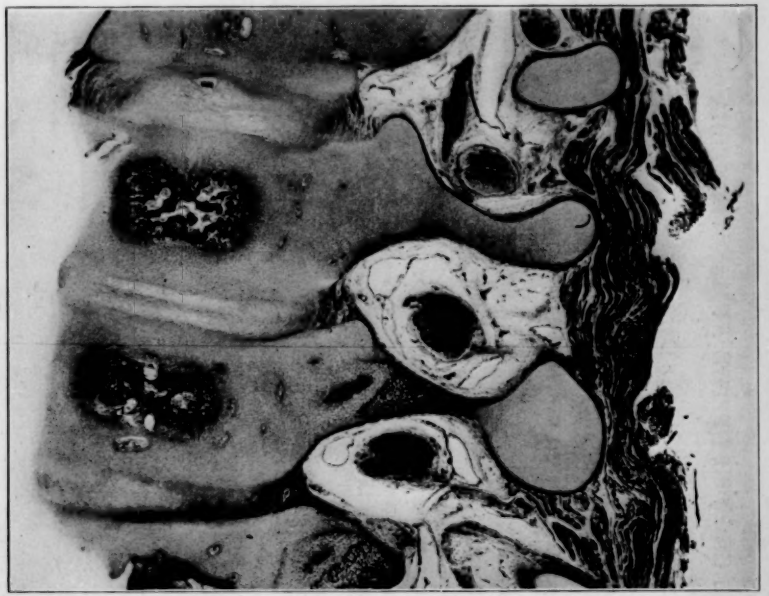

FIG. 3

Fig. 2: Photomicrograph (× 28) of specimen from 10.2-centimeter foetus, aged about fifteen weeks. Ossification appears about invading blood vessels forming the osteoblastic center, at first rather loosely spread behind advancing cartilage.

Fig. 3: Specimen (× 16) from 14-centimeter foetus, aged about eighteen weeks. Osteoblastic centers are consolidating and assuming the general shape of the vertebral body.

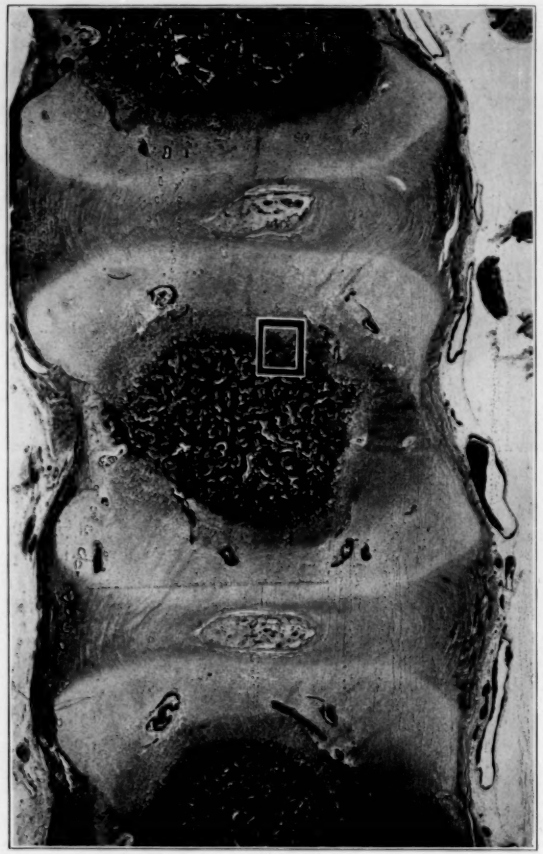

FIG. 4-A

FIG. 4-B

Fig. 4-A: Specimen (× 3) from 21-centimeter foetus, aged about twenty-five weeks. The osteoblastic center, actually its cartilaginous forerunner, now reaches from periphery to periphery. This corresponds in the long bones to reaching the cortex. At this time, columnar cartilage first appears in the form of an epiphyseal plate across its cephalic and caudal surfaces. The area within the black square is reproduced in Fig. 4-B under high power.

Fig. 4-B: High-power section of area marked on Fig. 4-A, showing the characteristic columnar cartilage formed between flat cartilage toward the surface of the vertebral body and the underlying and invading bone trabeculae.

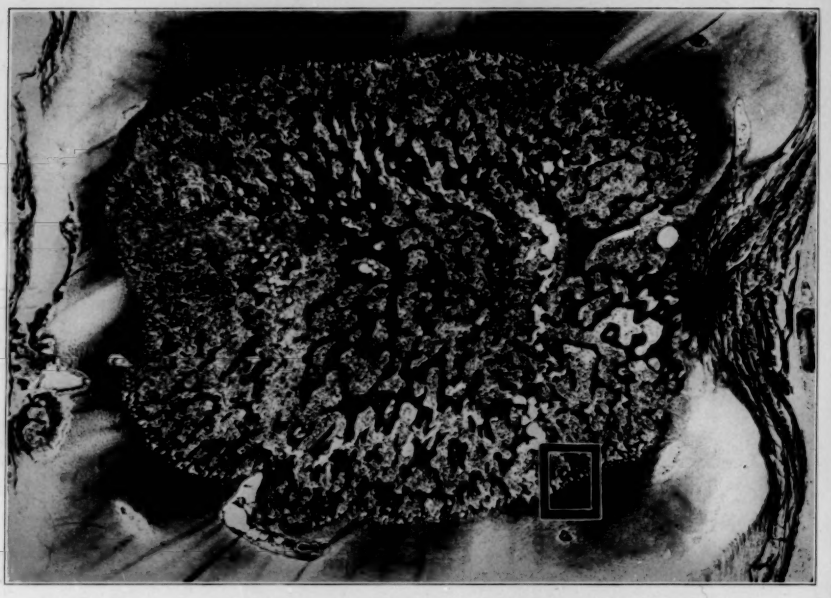

FIG. 5-A

Specimen (× 12) from four-day-old female. Epiphyseal-cartilage plate covers the cephalic and caudal surfaces of the osteoblastic center, and follows its anterior and posterior bowing to the peripheral indentations. Black square marks area reproduced in Fig. 5-B under high power.

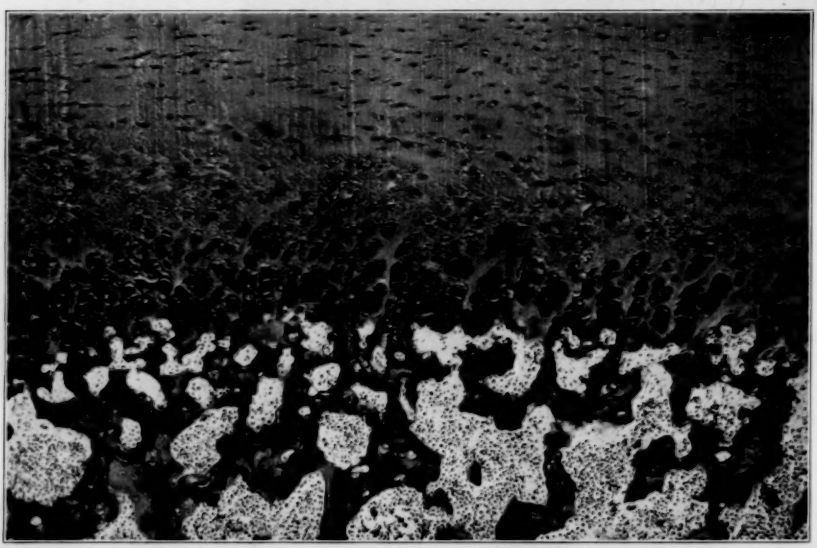

FIG. 5-B

High-power section of area enclosed in black square on Fig. 5-A, showing typical columnar cartilaginous epiphyseal structure.

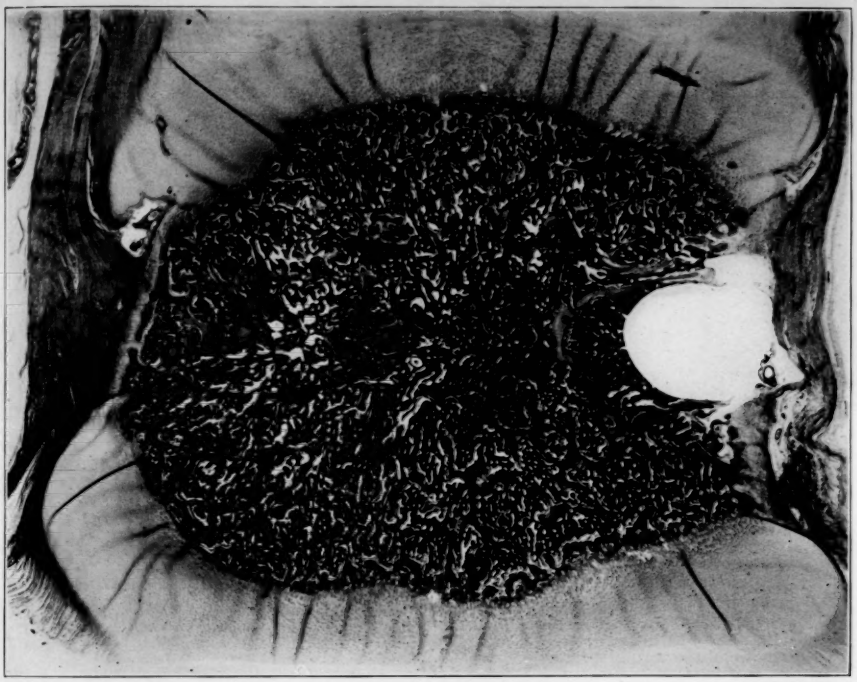

FIG. 6

Photomicrograph (× 20) of specimen from one-month-old male. Epiphyseal plates still present along cephalic and caudal surfaces of expanding osteoblastic mass.

tudinal growth of the body took place by enchondral development through epiphyseal plates. Descriptions of a few specimens were published, but others questioned Schmorl's conclusions. The polemic went on and Haas, in 1939, after studying the longitudinal growth of vertebrae in dogs, stated that the presence of a true epiphyseal plate in man had not been established. The present investigation has demonstrated, we believe conclusively, that Schmorl's contention is correct.

Fifteen plates are presented of specimens taken from fresh autopsy material in which death was known to have occurred from causes unrelated to pathological changes in the musculoskeletal system. The specimens were selected from a larger series, according to age intervals sufficient to demonstrate the growth of the vertebral body from the beginning of its ossification through its maturity. They range from that of an 8-centimeter foetus (C-R) **—that is, about fourteen menstrual weeks—to that of a female, twenty-three years old.

Figure 1 shows our earliest example of cartilage appearing in the mesenchyme. This, it must be remember, takes place after the provertebral elements have reformed into the structure which will eventually become a mature vertebral body. Figure 2 illustrates our earliest example of bone trabeculae being laid down about ingrowing blood vessels. Figure 3 shows further development of this osteoblastic center. Figures 4-A and 4-B show our earliest specimen in which the osteoblastic center, having approached the periphery, disclosed *characteristic columnar cartilage of a true epiphyseal plate* covering the cephalic

** The size of the foetus is given in terms of measurements from crown to rump (C-R), and is related to menstrual age in accordance with tables published in 1920 by Streeter.

FIG. 7

Specimen (× 8.5) from six-month-old male. Note fibers of anterior longitudinal ligament inserted into dip of cartilage plates at anterosuperior and antero-inferior corners. These are the sites of formation of the vertebral rings.

FIG. 8

Specimen (× 8.5) from thirteen-month-old male.

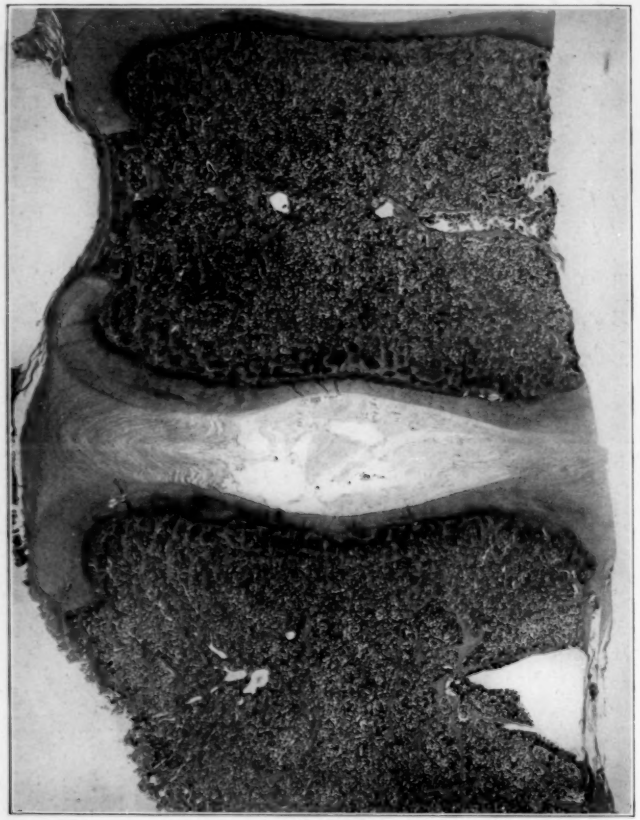

FIG. 9

Specimen (× 3) from five-year-old male. Surface cartilage is thinning out to relatively adult proportions. In this section the nucleus pulposus is particularly distinct in the intervertebral space.

FIG. 10

Specimen (× 3) from eight-year-old female.

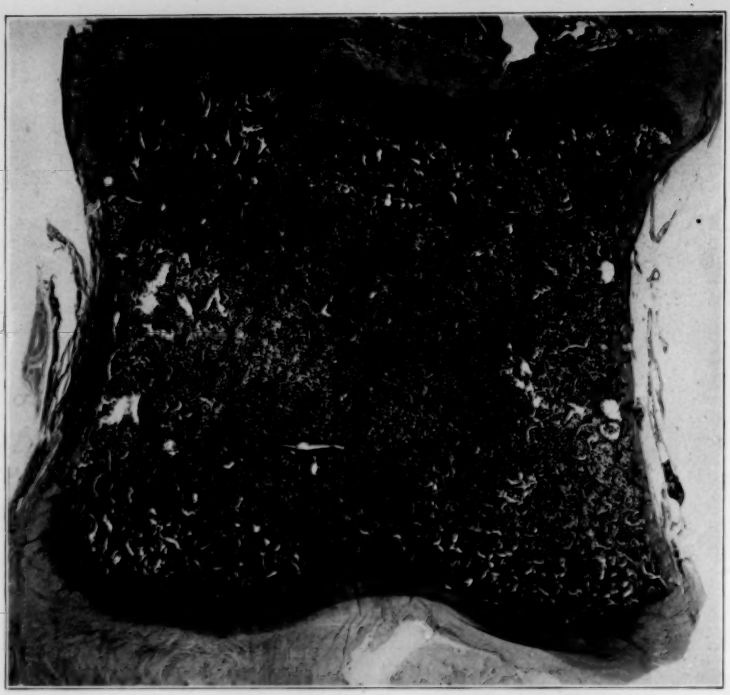

FIG. 11
Specimen (× 3.5) from thirteen-year-old male.

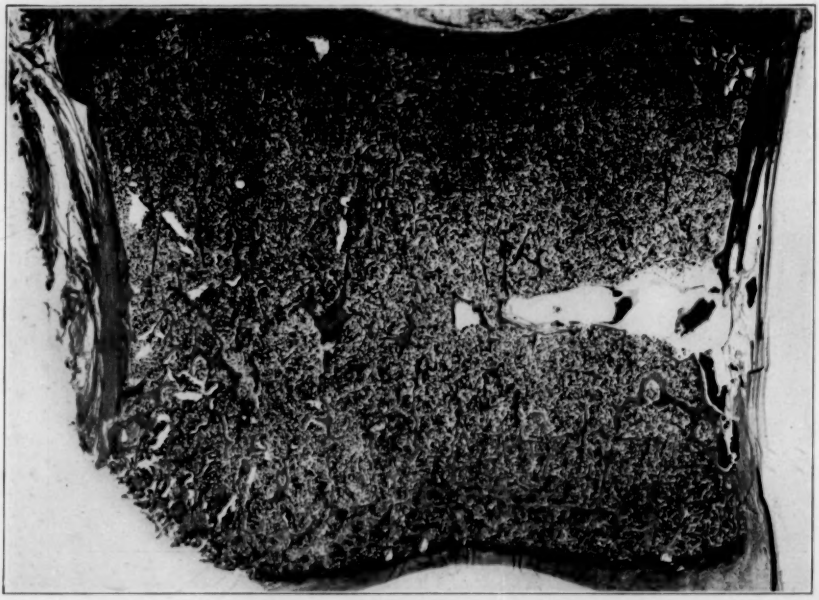

FIG. 12
Specimen (× 3) from fifteen-year-old male.

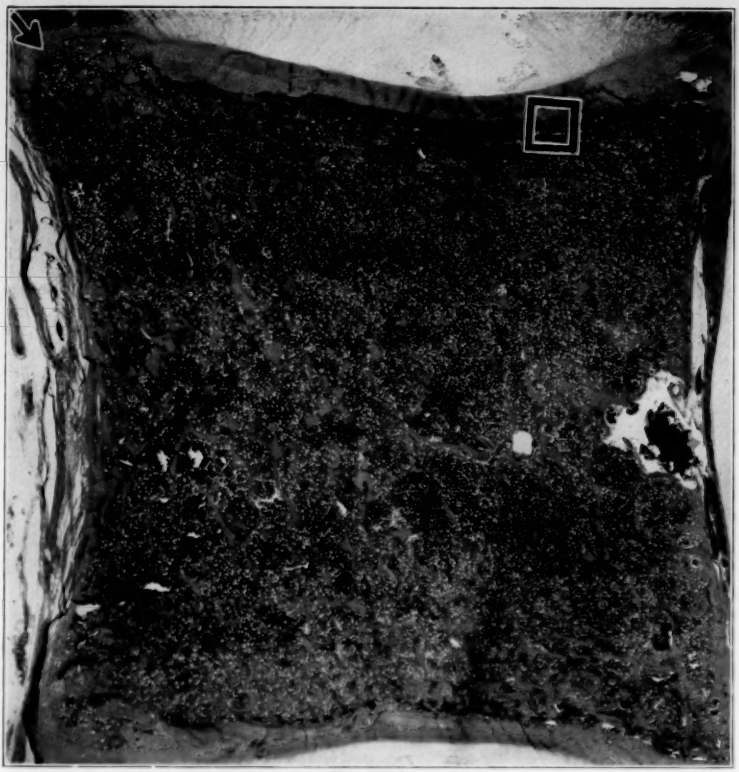

FIG. 13-A

Specimen (× 3.5) from seventeen-year-old female. Epiphyseal plate is beginning to disappear and subchondral bone plate is forming. The ossified vertebral ring (see arrow) is starting to fuse with vertebral body. (Black square marks area reproduced in Fig. 13-B.)

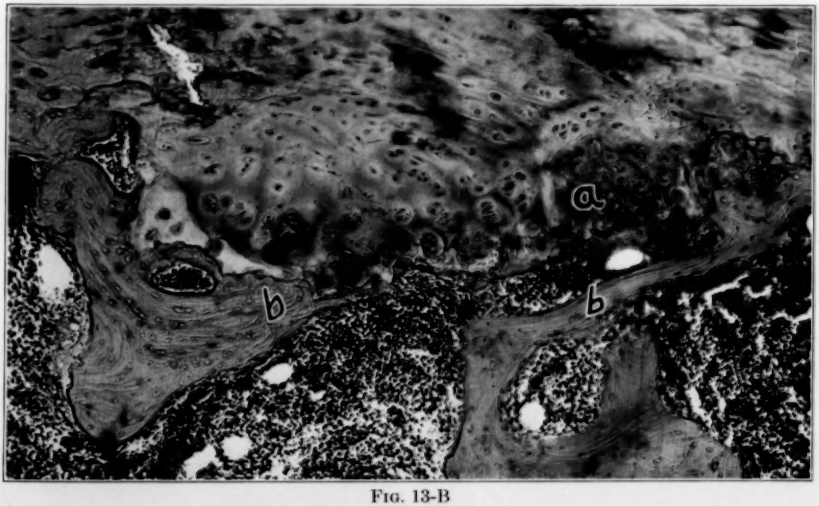

FIG. 13-B

High-power view showing (*a*) disappearing columnar formation of cartilage; (*b*) subchondral bone plate forming under surface of cartilage instead of new invading trabeculae.

FIG. 14

Specimen (× 3) from eighteen-year-old female. Epiphyseal plate has almost completely disappeared. Vertebral ring (see arrows) has almost completely fused to the body.

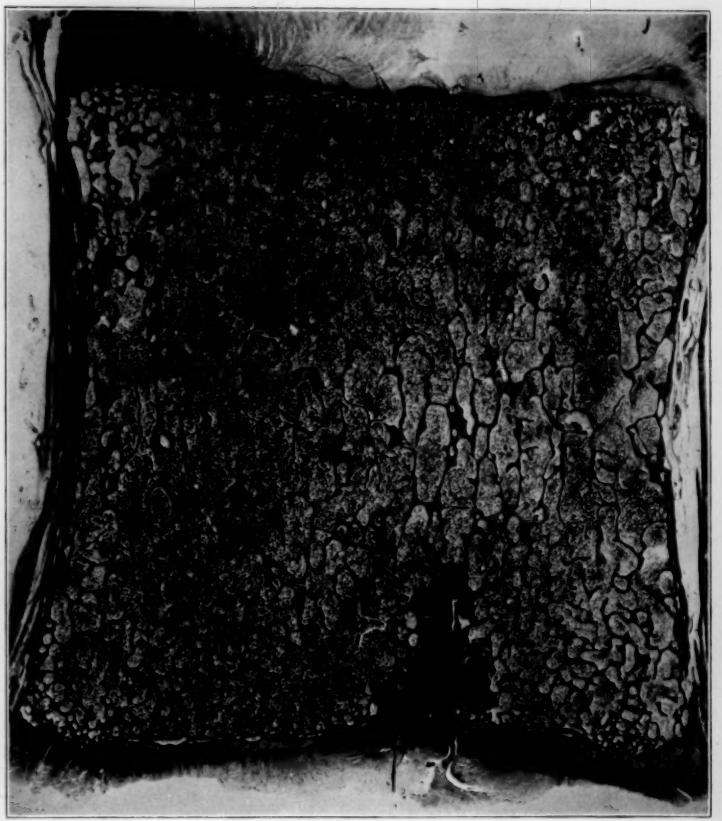

FIG. 15

Specimen (× 3.5) from female, twenty-three years old, showing normal adult vertebral body.

and caudal surfaces. All specimens taken at succeeding ages show the growing osteoblastic area preceded by the upper and lower epiphyseal plates until, in a seventeen-year-old female (Figs. 13-A and 13-B), the columnar formations [4] are disappearing and subchondral bone plates have been formed. Similar sagittal sections of each specimen of comparable age in our collection show the same structural development.

This sequence of specimens indicates that, in longitudinal development, the body of the human vertebra grows as does the diaphysis of a long bone, with true proximal and distal epiphyseal plates. Since this is so, the body of the human vertebra is subject to the same deforming factors which influence the growth of long bones elsewhere in the body. As a corollary, it follows that the same diseases, dyscrasias, metabolic or endocrine disturbances, and asymmetrical pressures of posture or contraction which disturb or retard the growing epiphyseal plates of long bones in other parts of the skeleton are operable on the bodies of the vertebrae. So apparently are the effects of roentgenotherapy.[1]

Although our sections were not cut to show best the histology of the roentgenographically prominent structures lying on the cephalic and caudal surfaces of the vertebral body, enough has been demonstrated to confirm Schmorl's views. The so-called "epiphyseal ring" of the vertebra is misnamed, and the label should be stricken from scientific terminology. The ring is not an epiphysis and takes no active part in the growth of the vertebral body. It is primarily a cartilaginous ring, which is ossified separately. Sometimes incomplete in circumference, it lies on the rims of the superior and inferior margins of the vertebral bodies. Schmorl [18] named the structure the *Randleiste;* this can be translated as the "rim molding". We would suggest a more easily remembered name, somewhat in keeping with established usage,—the *vertebral ring.*

In the authors' series of growing vertebral bodies, this structure bore no relationship to epiphyseal growth. It lies outside the metaphyseal area and fuses with the body when longitudinal growth is completed, between the seventeenth and twenty-third years (Figs. 13-A, 13-B, 14, and 15). It acts in this way precisely as do apophyses elsewhere in the skeleton. It, too, is a peripheral structure and, except at the rim of the vertebral body, does not lie in the axis of its longitudinal growth. Its function is still open to question, but in several of our sections the fibers of the anterior longitudinal ligament insert into its substance.

CONCLUSIONS

1. The longitudinal growth of the human vertebral body is depicted by a series of sagittally cut specimens taken from fresh autopsy material, ranging from one of an 8-centimeter foetus to one of a twenty-three-year-old adult.

2. Longitudinal growth of the vertebral body takes place by means of true epiphyseal-cartilage plates, as does longitudinal growth in the metaphyses of long bones.

3. The vertebral ring, often observed in the roentgenograms of growing vertebrae, is an apophysis rather than an epiphysis, and takes no part in the longitudinal growth of the vertebral body.

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DISCUSSION

Sympathetic Ganglionectomy in Poliomyelitis

(*Continued from page 802*)

the few who lost more than the original difference in length, the further change was in fractions of an inch, and much less than a plotted graph would have indicated over the remaining growth years.

The children selected were all under ten, and considerably remote from that age after which further shortening is never observed. They were selected primarily for prophylactic treatment, and experience has not suggested that any major degree of equalization could be expected from the procedure.

The series was interrupted by concern as to the late effects on fecundity and sexual capacity, although by now we are satisfied that such are absent. The hypothesis was also considered at that time, after a series of otherwise successful limb lengthenings, that a very weak limb had better be left short, and discrepancy alleviated by arrest on the good side. However, I believe now, in threatened length loss with minor motor impairment, that this measure of prophylaxis is well justified and is to be recommended.

The authors should be congratulated on a careful piece of observation, as well as on drawing conclusions which I believe can be supported.

Dr. John A. Reidy (closing): I want to thank the discussors for their kindness.

I agree with Dr. Peabody that the procedure is to be reserved for those patients with minor discrepancies and perhaps a minimal amount of weakness.

GRANULOMA RESULTING FROM THE USE OF TALC IN ORTHOPAEDIC SURGERY

BY J. ALBERT KEY, M.D., AND ROBERT H. RAMSEY, M.D., ST. LOUIS, MISSOURI

From the Department of Surgery, Washington University School of Medicine, St. Louis

The fact that talcum powder, accidentally implanted in the peritoneal cavity from the surface or interior of rubber gloves during an operation, may be the cause of troublesome or even fatal complications is now widely known by abdominal surgeons. However, this may not be true of orthopaedic surgeons. Seelig, Verda, and Kidd have stated that the dry-glove technique was in use for about twenty-five years before the evils of talc were discovered. It has taken about fifteen additional years for the knowledge that talc is an important operating-room hazard to become generally recognized by abdominal surgeons, in spite of the fact that, during the intervening years, several voices have cried in the wilderness of medical literature that "talc must be banished from the operating room".

The fact that talc may cause postoperative complications in other than abdominal wounds was first brought to the authors' attention in March 1947 by the surgical pathologist, reporting his findings on some tissue which we had excised in the belief that we were dealing with local recurrence of fibrosarcoma of the forearm. Several months later, another patient, who had had an unsuccessful operation for the removal of a protruding intervertebral disc, returned after a second disc operation with two draining sinuses in his back. The sinuses were excised; the wound was closed and healed satisfactorily. When the tissue from these sinuses was diagnosed as talc granuloma, we became interested in this condition, and have been able to identify three additional cases of talc granuloma as being the cause of readmission and reoperation on the Orthopaedic Service at the Barnes Hospital during the year 1947. The five cases are as follows:

CASE 1. A white male, twenty-five years old, entered the Hospital for removal of two nodules in the lower third of a scar on the volar surface of his forearm. Two and one-half months previous to this admission, the patient's forearm had been operated upon for the third time and block removal of a recurrent fibrosarcoma had been performed. The pathologist reported the nodules as talc granuloma. Six months later a true recurrence appeared in the arm, and an interscapular-thoracic amputation was performed.

CASE 2. A man, fifty-one years old, was readmitted to Barnes Hospital because of persistent low-back pain and sciatic pain which had not been relieved by a disc operation, three months previously. The disc was again operated upon; the postoperative course was uneventful and the wound healed. The patient returned later with three small sinuses in the wound. After removal of some subcutaneous silk, plus treatment by rest and penicillin, the sinuses improved sufficiently so that he was discharged at the end of eleven days. Ten days later, he returned with two draining sinuses, and a block dissection and suture of the wound were done. This wound has remained healed. The pathologist's report was talc granuloma.

CASE 3. A man, twenty-four years old, was operated upon for diastasis of the ankle, and the tibia and fibula were held together by a threaded wire with a nut on each end. Two and one-half months later, the patient was readmitted because the wire had broken and there was a painful swelling over the medial malleolus. At reoperation, a mass of grayish granulation tissue was removed from the area over the tibial end of the wire and nut. The pathologist's report on this tissue was talc granuloma.

CASE 4. A man, forty-one years old, was operated upon for an intervertebral-disc lesion and was discharged on the eighth postoperative day with the wound healed. After four days, pain and swelling appeared in the wound; he was readmitted nine days later with a draining sinus. A silk suture was removed; after treatment with sulfadiazine and hot packs, the sinus healed and he was discharged nine days later. After three days, an abscess appeared. He was readmitted and the sinus was excised; the wound was closed and has remained healed. The pathologist's diagnosis was talc granuloma.

CASE 5. A man, forty-one years old, was admitted for spine fusion because of persistent low-back pain and sciatica. He had been operated upon elsewhere nine months previously and the fourth lumbar disc had been removed. At operation, a mass of granulation tissue was removed from the site of the ligamentum flavum over the fourth disc. The spine was then fused. The pathologist's report was talc granuloma. It is possible

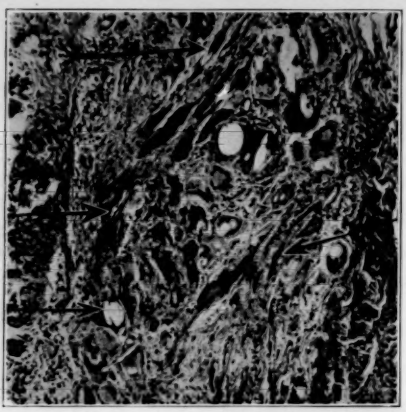

FIG. 1-A

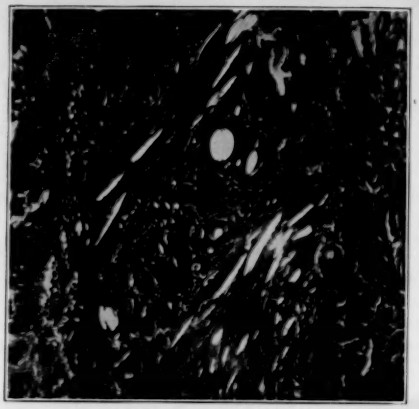

FIG. 1-B

Fig. 1-A: Low-power photomicrograph of deeper tissues from wall of sinus in Case 2. Note large number of foreign-body giant cells in the granulomatous tissue. Talc crystals are indicated by arrows.
Fig. 1-B: Many of the talc crystals lie free in the tissues and are brought into clearer view with polarized light.

that the granuloma had been the cause of this man's persistent symptoms and that the fusion was not necessary.

Our discovery of the cause of the trouble in these five cases is probably due to the fact that, during this period, Eiseman, Seelig, and Womack had just finished collecting thirty-seven cases of postoperative complications caused by talc in patients operated upon in Barnes Hospital. Consequently, sections of all granulomata were being examined under polarized light, as recommended by Fienberg, in order to accentuate the appearance of the birefringent talc crystals (Figs. 1-A to 3-B). Certainly many such cases must have occurred on our Service, but they were not recognized.

The first case of talc granuloma reported by Antopol was encountered while he was studying granuloma caused by Lycopodium spores. Lycopodium was formerly used for glove powder and was abandoned because of its tendency to cause granuloma. Since then, many similar cases have been reported. Several authors have produced the lesions experimentally and have studied the pathogenesis of talc granuloma. Lichtman and his associates noted extreme variability in the reaction of the host to talc and stated that, in some regions, it provoked a marked inflammatory response with many foreign-body giant cells, while in others it was engulfed in histiocytes with little surrounding reaction. They likened the nodules which they produced in dogs to tubercles without caseation, calcification, or pyogenic centers. They also noted that talc seemed to immobilize the engulfing phagocyte without destroying it, and that migration from the original site was limited. This explains the production of circumscribed granulomata, which may be activated by trauma or infection after long periods of quiescence. Seelig emphasized the property of talc to cause peritoneal adhesions, and stated: "There is probably no more dependable producer of fibrous adhesions than silica". In the peritoneal cavity, these adhesions bind the intestines together and to surrounding structures, and not only interfere with the function of the gut, but produce a characteristic gross pathological lesion. In orthopaedic wounds, on the other hand, no such characteristic gross lesion is produced and the diagnosis must be made from microscopic sections. Even there, it is apt to be missed unless the sections are examined under polarized light.

In rats, Saxén and Tuovinen noted that, if there is no tissue damage, a small amount of talc may disappear without a trace, but, if the tissues are crushed, a small amount of

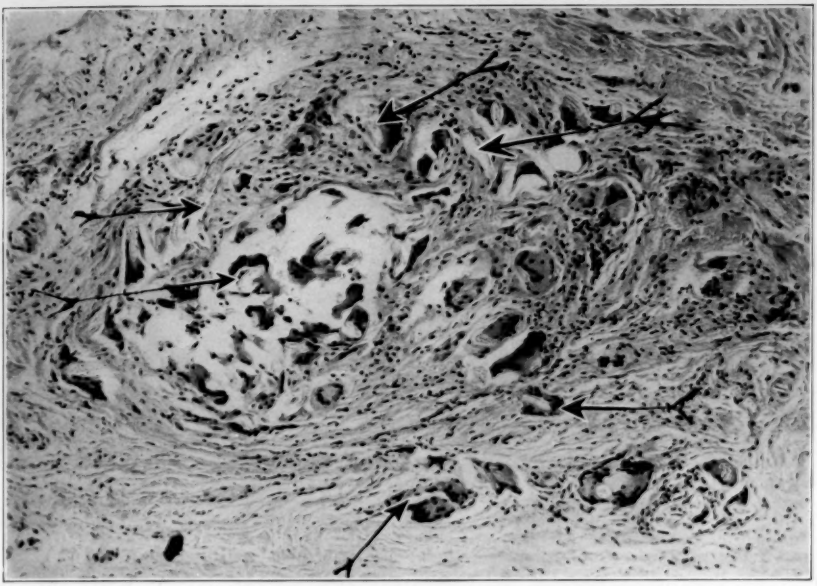

FIG. 2-A

A small nodule from Case 5. The circumscribed lesion might be likened to a tubercle. Talc crystals are indicated by arrows.

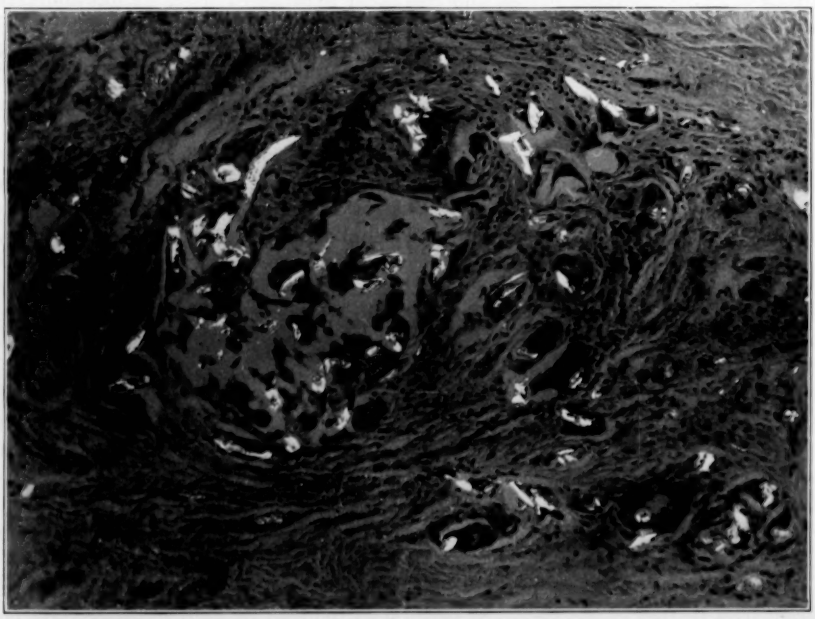

FIG. 2-B

The talc crystals are seen in this view, which was made with polarized light.

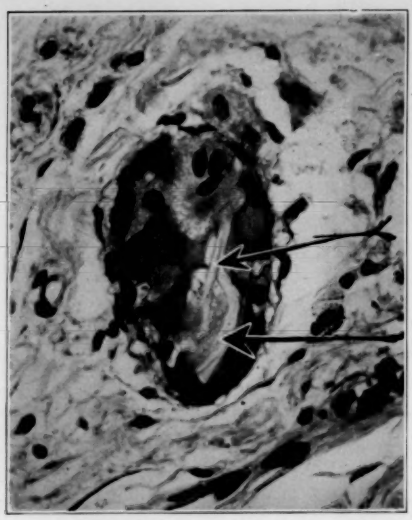

FIG. 3-A

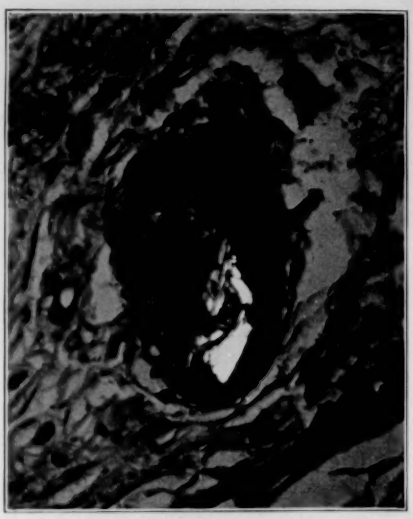

FIG. 3-B

Fig. 3-A: High-power view of a small giant cell containing talc crystals (Case 1). A few eosinophils are seen in the field. Talc crystals are indicated by arrows.
Fig. 3-B: Polarized-light photomicrograph shows the crystals more clearly.

talc will cause a granuloma. Large amounts of talc caused granuloma even without tissue damage. This is probably one explanation of the variation in the manner in which different individuals react to talc.

In three of the authors' cases, the condition manifested itself as granulomatous nodules; in two of them, the wounds healed by primary intention, then reopened and persistent sinuses formed. Ordinarily, we would have attributed these to mild infections.

Microscopically, the appearance is that of a productive inflammatory reaction. The tissue consists of a mass of histiocytes (epithelioid cells or macrophages), foreign-body giant cells, small round cells, and collagenic connective tissue. The collagenic fibers run in various directions and the tissue is not especially vascular. The microscopic appearance of the lesions varies with the duration and with the presence or absence of infection. Lesions of long duration contain more fibrous tissue; those of short duration or those which are complicated by infection are more cellular and may contain leukocytes and areas of necrosis. The talc crystals may lie free in the tissues or be surrounded by or engulfed in histiocytes or foreign-body giant cells. They are difficult to see in ordinary light, but are brought into sharp relief by polarized light. Unless this is used in examining the sections, the nature of the condition is apt to be missed, even by an experienced pathologist (Figs. 1-A to 3-B).

In tissue from an excised sinus, the surface layer presents the microscopic appearance of a pyogenic membrane; the giant cells and talc crystals are found in the depth of the tissue and are usually embedded in a network of collagenic fibers. In these deeper areas, leukocytes are not common and, among those present, there is apt to be an unusually large proportion of eosinophils. Most of the cells are small or medium-sized round cells, histiocytes, and giant cells. The giant cells are of the foreign-body type and may be quite large, fifty or more nuclei being visible in a single microscopic section.

The smaller and medium-sized talc crystals are often in the bodies of the giant cells; the larger ones lie free in the tissues or may be surrounded by histiocytes or giant cells. Apparently they do not cause death of the cells which surround or engulf them, and their effect on the tissues appears to be largely mechanical. Characteristically, in the older

lesions small nodules, such as those illustrated in Figures 2-A, 2-B, 3-A, and 3-B, are scattered through the mass of interlacing collagenic fibers.

In an effort to learn more about postoperative wound infections, Weed and Groves examined 35,763 gloves which had been used in 4,549 operations over a period of twenty months. They found that one glove or more was torn in 74.4 per cent. of the operations, and that 22.6 per cent. of the gloves were torn. Seelig estimated that a finger of a carelessly prepared glove might contain from 50 to 100 milligrams of talcum powder, so it is easy to understand why the operative wound is contaminated with the powder.

Seelig, Verda, and Kidd recommended the use of cream of tartar (potassium bitartrate) as a substitute for talcum powder in the operating room and also experimented with starch, but found that this gelled on autoclaving. The cream of tartar did not cause any reaction in the tissues, but it was expensive and shortened the life of the gloves. Recently, efforts to modify starch powder in such a manner that it can be autoclaved without losing its powdering qualities have been successful. Lee and Lehman and MacQuiddy and Tollman have shown experimentally that a corn-starch powder is readily absorbed in the tissues; it does not cause intestinal adhesions or granulomatous lesions, nor does it interfere with the healing of operative wounds. They concluded that it is a safe replacement for talc for surgical and other purposes.

After becoming aware of the dangers, the authors continued to use talc in the operating room for lack of a satisfactory substitute, but these precautions have been adopted:

1. Nurses are cautioned not to leave excess talc in the fingers of gloves.

2. Gloves and a small shaker of talc are placed on a table near the door of the operating room, well away from the operative field and from the instrument table and dressing tables.

3. Nurses are instructed to use as little powder as possible in powdering the hands and to avoid scattering the powder in the air.

4. A splash basin is placed next to the glove table. The surgeon and nurse wash their gloves after putting them on and dry them with a sponge, which is discarded. This washing is repeated each time the nurse returns to the glove table.

5. After the operation is finished, the wound is washed thoroughly with a saturated aqueous solution of sulfanilamide before it is closed.

We realize, with Seelig, that talc spreads in the air and that some is left on and in the gloves in spite of the precautions just described, but we used talc under these conditions for over a year without recognizing a single case of talc granuloma, a sinus, or a failure of wound healing which had been caused by talc. We are now using a starch powder.

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EMBRYOLOGICAL DEVELOPMENT OF THE TENDINOUS APPARATUS OF THE FINGERS

Relation to Function*

BY EMANUEL B. KAPLAN, M.D., NEW YORK, N. Y.

From the Department of Anatomy, College of Physicians and Surgeons, Columbia University

The motion of a normal human hand is the result of simultaneous action of muscle groups. This was well described and explained by Duchenne of Boulogne in 1867, and even earlier. The muscles act through tendinous structures which are arranged into an extensor apparatus, a flexor apparatus, and the adductor-abductor auxiliary.

The flexor apparatus consists of two flexor tendons—the sublimis, perforated in an oblique direction, and the profundus, perforating the sublimis—both enclosed in a narrow tunnel intimately connected with the periosteum of the phalanges and the volar portion of the metatarsophalangeal and interphalangeal joints.

The abductor-adductor auxiliary is a dependent of the extensor apparatus, with the addition of the lateral insertions of the interossei into the bases of the proximal phalanges.

The extensor apparatus is not enclosed in a tunnel. Its chief component is the tendon of the extensor communis, which has a sheetlike expansion over the metacarpophalangeal joint and the proximal phalanx. This expansion is spread over the sides of the metacarpophalangeal joint, where it is joined by the tendon and the sheetlike expansion of the interossei. The expansion ascends on each side of the proximal phalanx of the finger.

About one-third of the length of the proximal phalanx distal to the base of the phalanx, the expansion shows a condensation of the fibers in the middle of the dorsum along the long axis of the proximal phalanx, called the middle band; and also condensation of the lateral edges, called lateral bands. The middle band stops at the dorsal base of the middle phalanx. The lateral bands are joined by the tendons of the interossei and form an inseparable unit, ascending from the volar aspect of the sides of the metacarpophalangeal joint. They are directed toward the dorsal aspect along the sides of the proximal interphalangeal joint, and then continue their course over the dorsum of the middle phalanx and over the distal interphalangeal joint for insertion into the dorsal base of the distal phalanx. On the radial side of the proximal phalanx, the lateral band is joined by the tendon of the lumbricalis, distal to the junction of the corresponding tendon of the interosseus. It is impossible to separate the lateral bands into an extensor, interosseus, and lumbrical tendon by gross dissection, or to recognize such a division.

Over the dorsum of the proximal phalanx, between the middle band of the extensor apparatus and the lateral bands, are found transverse and arciform fibers. The fibers permit a limited range of independent distal and proximal action between these two structures, so that complete traction of the middle band does not produce complete tension of the lateral bands of the extensor apparatus (Fig. 1). Full extension of the extensor communis thus permits only hyperextension of the proximal phalanx and some extension of the middle phalanx, which varies in individuals and may reach 160 to 170 degrees; however, the distal phalanx appears not to be influenced by this action and remains in flexion. In cadaver experiments or during surgical procedures, if the lateral bands are pulled in a proximal direction after full extension of the extensor communis over the metacarpophalangeal joint, they produce complete extension of the distal and middle phalanges.

The disposition of the entire dorsal apparatus in relation to the transverse axes of

*Read at the Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., February 10, 1950.

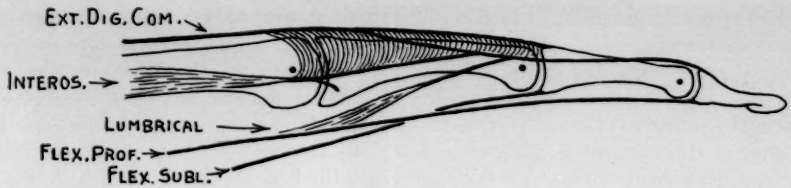

FIG. 1

Lateral diagrammatic view of the metacarpophalangeal joint and two interphalangeal joints showing the extensor apparatus, interosseus, lumbrical, and flexor tendons. It also shows the transverse axes of rotation of these joints and the balancing forces for each joint:

1. Lateral bands of the extensor apparatus against flexor profundus at the distal joint.
2. Middle band of the extensor digitorum against flexor sublimis at the middle joint.
3. Extensor digitorum against interossei and lumbricals with the flexors at the metacarpophalangeal joint.

The arciform fibers uniting the middle band with the lateral bands are also shown in a schematic view.

rotation of the metacarpophalangeal, proximal, and distal interphalangeal joints is of great interest. At the metacarpophalangeal joint, the pull of the lateral bands is volar to the transverse axis, thus producing flexion of this joint. The pull of the lateral bands is dorsal to the axes of rotation of the proximal and distal phalangeal joints. This disposition explains the peculiar action of the interossei and lumbricals, which consists in simultaneous flexion of the metacarpophalangeal joint and extension of the proximal and distal interphalangeal joints, as observed in paralysis of the radial nerve or on isolated strong electrical stimulation of the interossei.

When the hand is closed into a fist, the gradual extension of the distal and middle phalanges is in the most favorable situation for action of the interossei, because the metacarpophalangeal joint is flexed; the interossei further flex this joint and extend the distal phalanx. The simultaneous action of the extensor digitorum communis, acting predominantly on the metacarpophalangeal joint, overcomes the flexor component of the interosseus, extending the metacarpophalangeal joint. It also acts on the proximal interphalangeal joint, while the interosseus extends the distal and middle phalanges. The result is simultaneous extension of the three phalanges of the finger, due to the action of the extensor communis on the proximal and middle phalanges and to the action of the interosseus on the distal and middle phalanges.

In the coordinated activity of the entire finger, there are three areas of balance (Fig. 1). Acting on the base of the distal phalanx, two forces are in balance,—the fused lateral bands of the extensor apparatus dorsally, the flexor profundus volarly. Acting on the base of the middle phalanx,—the middle band of the extensor communis dorsally, the flexor sublimis volarly. Acting on the base of the metacarpophalangeal joint,—the extensor communis dorsally and the interossei and lumbrical volarly, with the addition of the long flexors in certain circumstances. The predominance of action of one of the forces will tend to produce motion in the direction of the stronger force. The disruption of the balance at each joint will create a typical disability at the corresponding joint. For instance, the loss of continuity of the lateral bands with the dorsal base of the distal phalanx will create a baseball, or mallet-finger deformity; the loss of continuity of the middle band, proximal to the base of the middle phalanx, will create a flexion deformity of the proximal interphalangeal joint with extension of the distal phalanx.

Although the lumbrical muscle is usually described as either a flexor of the metacarpophalangeal joint or a flexor of this joint and extensor of the two distal joints of the finger, its actual work is difficult to observe. Its position between the extensor apparatus and the profundus theoretically places it in a position of an immediate coordinator between these two systems. It is not known definitely whether the lumbricalis contracts when the flexor profundus contracts, or whether it acts simultaneously with the interossei

and the extensor communis. It is very difficult to observe this directly. The author had occasion to stimulate the lumbricals in the human with a faradic current in the process of surgical procedures, and in the Rhesus monkey experimentally. The results were similar to those obtained by stimulation of the interossei,—namely, flexion of the metacarpophalangeal joint and extension of the two distal phalanges, but without lateral deviation of the finger. However, it was difficult to stimulate the lumbrical simultaneously with the flexor profundus or the extensor communis to see the behavior of this muscle under combined action.

In ordinary activity, extension of the fingers requires speed; flexion requires force. It is possible that, if the lumbricals contract in rapid extension, they pull the flexor profundus tendon distally and expedite extension of the distal phalanx. If the lumbrical contracts simultaneously with the flexor profundus during flexion of the distal phalanx, it may produce better stabilization of the distal phalanx by tension of the distal portion of the extensor apparatus for more forceful action.

Experimentation on hands in fresh cadavera shows that traction in a proximal direction, applied to the extensor communis tendon over the metacarpal, produces hyperextension of the proximal phalanx, then marked extension of the middle phalanx and minimal action on the distal phalanx, which remains flexed. Traction applied to the lateral bands, with the extensor communis maintained in traction, produces complete hyperextension of the proximal and distal phalanges. If the entire extensor apparatus is divided completely across the middle phalanx distal to its base, traction applied to the extensor communis over the metacarpal produces hyperextension of the proximal phalanx and extension of the middle phalanx.

If, however, the dorsal apparatus is divided transversely and completely over the middle of the proximal phalanx, traction applied to the tendon of the extensor communis does not produce extension of the middle phalanx, but only strong hyperextension of the proximal phalanx.

Duchenne was the first to call attention to the relation of the extensor communis tendon to the dorsal base of the proximal phalanx. He found that there was almost a constant insertion of the extensor communis into the base. Many investigators have found that this insertion is not constant. The author reported [4, 5] that approximately one third of a fairly large series of human hands showed a variable non-tendinous connection of this type, and confirmed that the extensor apparatus, as a whole, has intimate connections with the capsule of the metacarpophalangeal joint. The precise nature of these connections and the relation of the extensor apparatus to the proximal interphalangeal joint were not investigated. These two areas, however, demanded further elucidation.

Several years ago, the author constructed a working model of a hand in the hope of clearing the obscure elements in the mechanism of the hand and then using the apparatus for instruction. The construction proved to be more difficult than anticipated. Repeated efforts to reproduce the anatomical details in structure and functional length of the moving parts failed to result in a smoothly moving unit. Although the problem was solved only partially, a few important facts not previously suspected were learned in the process of construction.

The experiments on the cadaver, the experiences with the construction of a working model of the hand, and observations of paralytic and traumatic lesions, as well as the variety of views expressed in the literature [1, 4, 6, 8, 9], indicated that more information on the relationship of the dorsal apparatus to the metacarpophalangeal and proximal interphalangeal joints is needed for better understanding of function. To analyze these structures with more precision, foetal human hands were thought to be suitable material. Actual differentiation of joints and of muscular and tendinous structures is not sufficiently evident in early embryos, but embryos of about 40 millimeters, corresponding to the age of nine weeks, begin to show some tendinous pattern [3, 7].

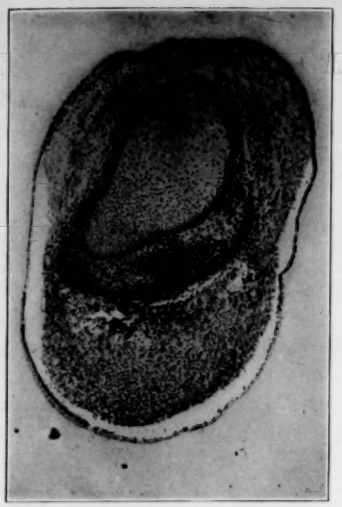

FIG. 2-A

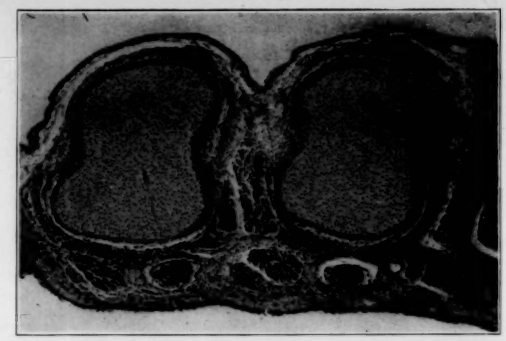

FIG. 2-B

FIG. 3-A

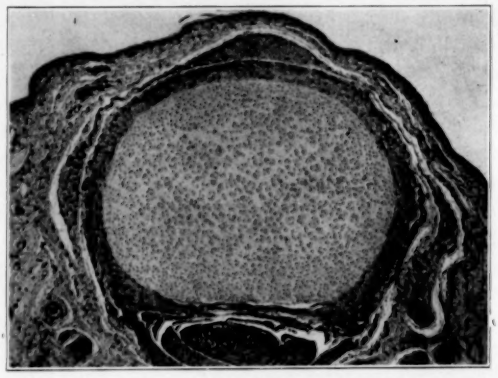

FIG. 3-B

METHOD OF INVESTIGATION

Our series included several embryos from 40 to 120 millimeters in size, corresponding to nine to sixteen weeks of intra-uterine development. The extensor and flexor muscles and also the intrinsic muscles of the hand are differentiated in the 40-millimeter embryos. The tendinous apparatus of the dorsum of the fingers and the relationship to the capsular and periosteal structure begin to develop later, and in the older embryos are similar to the adult arrangement. The connections and relationship of the tendinous structures to the capsule of finger joints and periosteum have an important bearing on the function of the fingers. A large number of serial sections at intervals of 6 millimicra were made through the fingers and were studied for development of the dorsal apparatus, appearance of the interossei and lumbricals, and flexor tendons. Hematoxylin-eosin and Masson stains were used. Definite impressions were obtained, but further study will be required.

1. It was impossible to find separate tendons in the lateral bands which could be interpreted as specific for the interossei or lumbricals.

2. The flexor tendons appeared to differentiate simultaneously into a flexor sublimis and flexor profundus from a common mass which also included the flexor-tendon sheath; there was no outgrowth of the tendons from corresponding muscles. The profundus tendon in the fingers was frequently divided into two components, similar to the sublimis tendon.

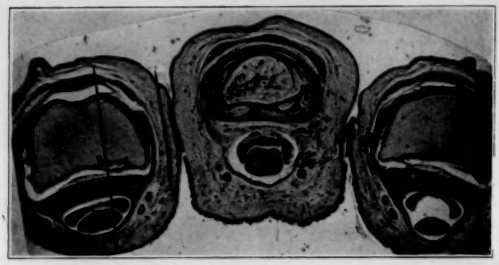

FIG. 4-A

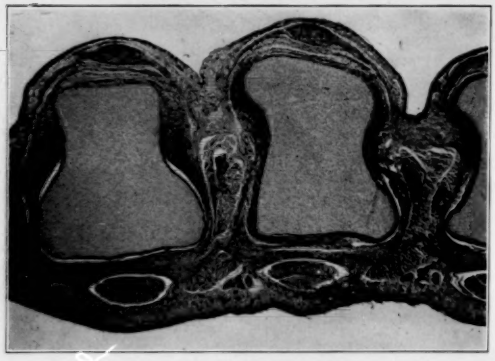

FIG. 4-C

FIG. 4-B

3. The extensor apparatus appeared to evolve spontaneously from a common mass with more condensation in the middle and gradual extension toward the sides.

Representative sections of the interphalangeal and metacarpophalangeal joints in foetus at various stages of development showed the gradual changes and final arrangement of the tendinous structures and their relation to the perichondrium and joints of the fingers.

A section of the middle finger through the distal part of the proximal phalanx in a nine-week foetus under moderate magnification (Fig. 2-A) shows the dorsal aponeurosis as a condensation of fibers with a tendency toward surrounding the phalanx. The flexor tendons are developing in a mass of cells which will further differentiate into the flexor sheath and the tendons.

A section through the heads of the metacarpals involving the metacarpophalangeal joints of the same foetal hand under lesser magnification shows that the interossei and lumbricals are already in evidence (Fig. 2-B). The tendon of the extensor digitorum communis is well differentiated and the dorsal apparatus shows a variety of fibers connected with the extensor tendon. Fibers unite the tendons of the extensor with the capsule of the joint, collateral ligaments, interossei, and the tunnel of the flexor tendons.

A section through the middle of the base of the proximal phalanx in a twelve-week foetus shows the undifferentiated dorsal apparatus (Fig. 3-A). It is impossible to see the middle band and the lateral bands separately, because the dorsal apparatus shows a continuous thick plate with fibers between the apparatus and the periosteum. These

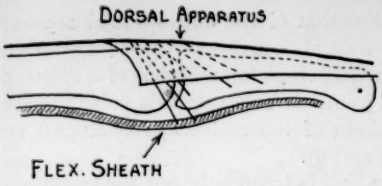

FIG. 5

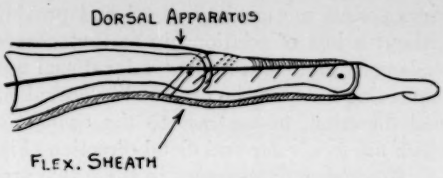

FIG. 6

Fig. 5: Lateral diagrammatic view of the enlarged metacarpophalangeal joint with the tunnel of the flexors underneath, the dorsal apparatus laterally, and the connecting fibers represented by broken lines to show that they are deep to the dorsal apparatus. These fibers are directed volarly and distally and run to the base of the proximal phalanx, to the capsule, to the periosteum, and to the palmar ligament (tunnel of the flexor tendons).

Fig. 6: Diagrammatic view of the proximal and distal interphalangeal joints (lateral view) shows the connecting fibers of the dorsal apparatus running obliquely in a volar and proximal direction, uniting this apparatus to the periosteum, tunnel of the flexors, and capsule of the proximal interphalangeal joint.

fibers represent in all probability the early connection between the dorsal apparatus and the dorsum of the base of the proximal phalanges.

In the same twelve-week foetus, a view of the structures of the head of the proximal phalanx just proximal to the proximal interphalangeal joint reveals a continuous sheath uniting the dorsal band of the extensor digitorum with the lateral bands (Fig. 3-B). It is impossible to see separate fibers for the interosseus and lumbrical tendons in the lateral bands. On the left side of the illustration, the fibers appear to continue into the surrounding tissues and toward the flexor tunnel.

A section through the proximal interphalangeal joints of the index finger and ring finger and the distal third of the proximal phalanx of the middle finger in a sixteen-week foetus shows the relationship of the dorsal apparatus in these areas (Fig. 4-A). In the middle finger, the dorsal apparatus shows the three bands united into a continuous structure with fibers running to the tunnel of the flexor tendons on the left and toward the periosteum on the right. Over the proximal interphalangeal joint of the index finger, the intra-articular cartilaginous meniscus connected with the middle band is well visualized. The continuation of the fiber around the phalanx toward the tunnel of the flexor tendons is readily seen. A section of the index finger delineated between two vertical lines and represented in Figure 4-B under greater magnification shows the connection of the dorsal apparatus with the tunnel of the flexor tendons. A section through the metacarpal heads over the metacarpophalangeal joints of the same sixteen-week foetus shows the fibers of the extensor apparatus running from the tendon of the extensor digitorum toward the collateral ligaments of the joint, toward the interossei, and toward the capsule (Fig. 4-C).

The reconstruction of the fibers, as observed in the numerous sections, permits the visualization of two important mobile points of anchorage of the extensor apparatus. The first anchorage is developed in the metacarpophalangeal area (Fig. 5). Over the metacarpophalangeal joint, deep to the tendons of the interossei, the extensor tendon is united by half-encircling fibers to the capsule and to the palmar ligament (tunnel of the flexor tendons). These fibers play a double function: They stabilize the tendon over the joint and also, by traction on the capsule, permit extension of the proximal phalanx. Additional stabilization is produced by the insertions of the tendons of the interossei into the lateral aspect of the base of the proximal phalanx, when these muscles contract simultaneously. This stabilization of the extensor apparatus is of great importance, because it is equally effective in extension and flexion of the metacarpophalangeal joint.

The other area of anchorage is found over the proximal interphalangeal joint (Fig. 6). Here the extensor apparatus is anchored to the capsule by long oblique fibers, uniting the lateral bands to the central band of the extensor communis near and at its insertion into the dorsal base of the middle phalanx; and also connecting the bands to the capsule of this joint and to the tunnel of the flexor tendons. The length and obliquity of these

fibers permit motion in a distal and proximal direction of the entire dorsal apparatus without a loss of relationship to the transverse axis of rotation of the proximal interphalangeal joint in a limited volar-dorsal motion. In complete extension of a finger, the connecting fibers of the proximal interphalangeal joint run obliquely in a volar and proximal direction, in contrast to the connecting fibers of the metacarpophalangeal area, which are in a volar and distal direction (Figs. 5 and 6).

Reconstructive surgery in these two areas, which is frequently not successful, must include restoration of the fine connections of the dorsal apparatus with the metacarpophalangeal and proximal interphalangeal joints.

SUMMARY

A study of the development of the tendinous apparatus of the fingers in foetal hands at various stages showed a definite pattern of fibers connecting the dorsal apparatus with the metacarpophalangeal and proximal interphalangeal joints. The connection has an important bearing on the function of the fingers, and must be considered in surgical reconstruction in these areas.

NOTE: The author wishes to express his gratitude to Professor Wilfred Copenhaver for his valuable help in preparing and photographing the slides.

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CLUB-FOOT

An Embryological Study of Associated Muscle Abnormalities *

BY CHARLES O. BECHTOL, M.D., AND HARLAN W. MOSSMAN, PH.D., MADISON, WISCONSIN

From the Department of Anatomy and the Orthopaedic Division of the Department of Surgery, University of Wisconsin

The purpose of this paper is to present the findings in two foetus with club-foot, in each of which an abnormal development of the skeletal muscle is associated with the club foot. In the descriptions by Böhm, Hackenbroch, and Mau of a number of foetus with club-foot, no abnormal microscopic findings in skeletal muscles are mentioned. Middleton, however, has reported prenatal lesions of striated muscle as a cause of several types of congenital deformities.

At our present state of knowledge regarding congenital deformities, it would be unwise to try to draw definite conclusions from these foetal observations.

It is of great importance to add our microscopic observations in both prenatal and postnatal examples of congenital deformities. Only by the accumulation of such observations will the abnormalities of striated-muscle development be placed in their proper relationship with other causes of congenital deformities. In this regard, it is suggested that the anterior muscles of the lower extremity in congenital posterior bowing of the tibia and the adductor muscles in congenital dislocation of the hip be investigated for signs of abnormal muscle development.

A second field in which there is need for more specific knowledge is that of the causes of recurrence in club-foot. The possibilities, as indicated by the foetus studied and by a review of the literature, are presented.

FOUR-MONTH FOETUS

In addition to club-foot, this foetus presents multiple abnormalities in joint position (Fig. 1-A). The scapulae are elevated, the arms and legs have failed to rotate from their early foetal position, both wrists are dorsiflexed, and club-foot is present unilaterally.

After removal of the skin and subcutaneous tissues, marked deficiency is seen in the volume of the muscles (Fig. 1-B).

This combination of findings makes it very probable that this foetus represents an early stage in the development of arthrogryposis [8,14,15].

Microscopically some of the muscles were retarded in their stage of development [6]. In each individual muscle, all fibers were at the same stage of development. Figure 1-C is a photomicrograph of two adjacent muscles, with drawings of the muscle fibers themselves. The fibers in the upper muscle are hollow, have centrally placed nuclei, and are budding. This muscle has been retarded and is at the thirteen-week stage of development. The lower muscle fibers are solid and have peripheral nuclei. They are at the sixteen-week stage of development, corresponding with the estimated age of the foetus.

Difference in the degree of maturity of muscle groups is the apparent cause of the club-foot and the dorsiflexed positions of the wrists. The more mature fibers must exert a stronger pull, for in each case the deformity is toward the more mature muscles.

This, however, is not the apparent cause of the elevation of the scapulae or of the failure of rotation of the limbs. All these muscles are at the sixteen-week stage. As Badgley has suggested, retention of early foetal positions may be on the basis of insufficient muscle volume to produce the descent of the scapulae and rotation of the limbs.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 14, 1950.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Four-month foetus with multiple deformities.
Fig. 1-B: Following removal of skin, the marked deficiency in muscle tissue may be seen.

Gross Examination

An 11-centimeter (crown-rump) foetus with an estimated foetal age of sixteen weeks showed multiple skeletal deformities (Fig. 1-A). Compared to normal foetus of this same age, there was a deficiency in the volume of all skeletal-muscle tissue (Fig. 1-B). Abnormal positions of several joints were observed. There was a club foot on the right and both wrists were dorsiflexed. There were also examples of retention of the early foetal position. The scapulae were elevated. The arms had only partially rotated from their early foetal position, and the legs had undergone almost no rotation. A dissection, including all viscera, the brain, spinal cord, and eye, showed no other gross abnormalities.

Microscopic Examination

Multiple sections were made through body and limbs. Although most of the trunk muscles were at the same stage of development, which is characteristic of a sixteen-week foetus, some muscles of the extremities were retarded and showed a stage of development normally seen at thirteen weeks [6] (Fig. 1-C). All fibers of any single muscle were at the same stage of development, the only exception being that muscle spindles in all muscles were at the sixteen-week stage. Silver staining showed no abnormality in the nerves or motor end plates of any muscle [18]. Microscopic sections of all viscera, the brain, spinal cord, and eye showed no abnormalities.

Relation of Muscle Abnormality to Deformities

As regards the dorsiflexion of the wrists and the club foot, retarded development of some muscles had apparently led to an imbalance of opposing muscle groups. The more mature muscles presumably had greater tension and thus had pulled the joints into the deformed position. This factor of muscle imbalance apparently did not affect the retained foetal positions, since all muscles about the shoulder and hips were at a normal stage of development. The muscle volume and consequently muscle force were presumably insufficient to cause the changes from the early foetal position.

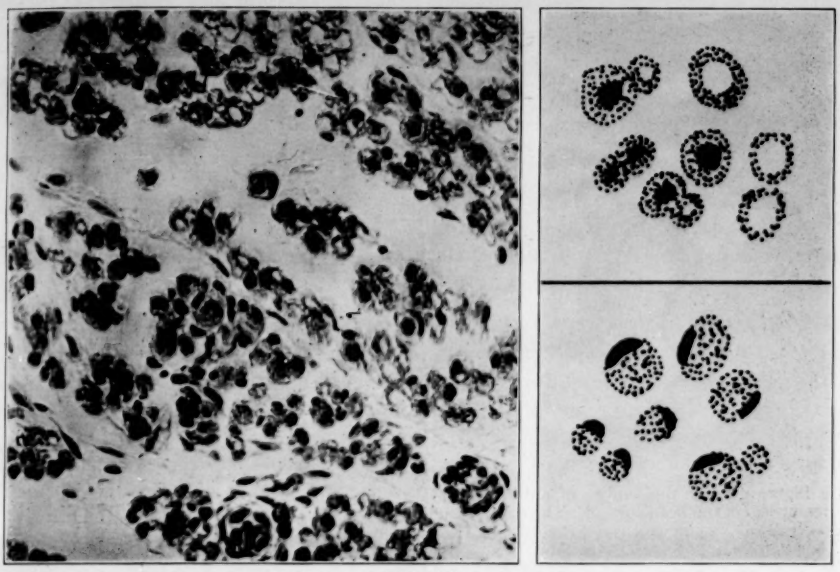

FIG. 1-C

Photomicrograph (× 150) with corresponding drawing. The upper fibers are hollow, have central nuclei, and are budding. This muscle is at the thirteen-week stage. The lower fibers are solid with peripheral nuclei; they are at the sixteen-week stage. Muscles are from the forearm.

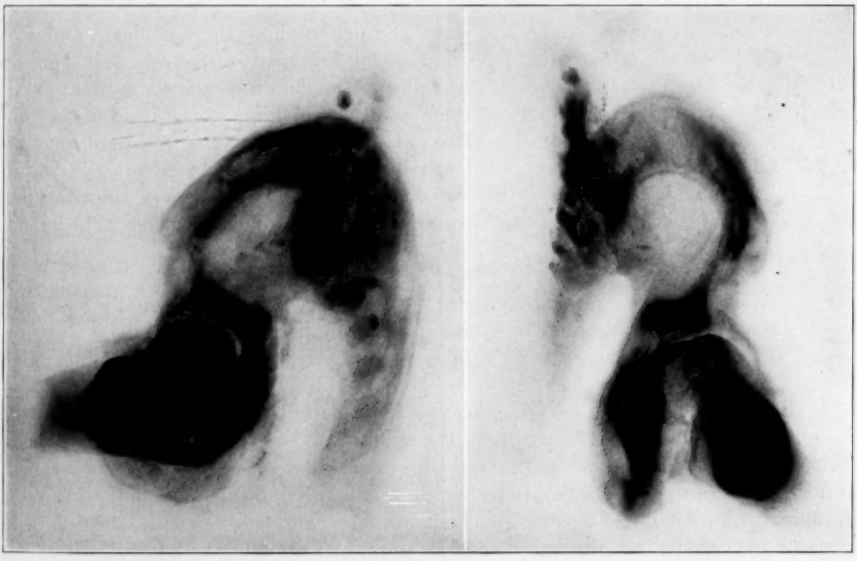

FIG. 1-D

Front and side views of stained pelvis from four-month foetus. Femur is externally rotated 90 degrees, bringing the greater trochanter closer to the obturator foramen.

Development of Joints

The joints of the extremities were somewhat retarded in development, being at about the twelve-week stage as compared to the estimated foetal age of sixteen weeks [19]. In

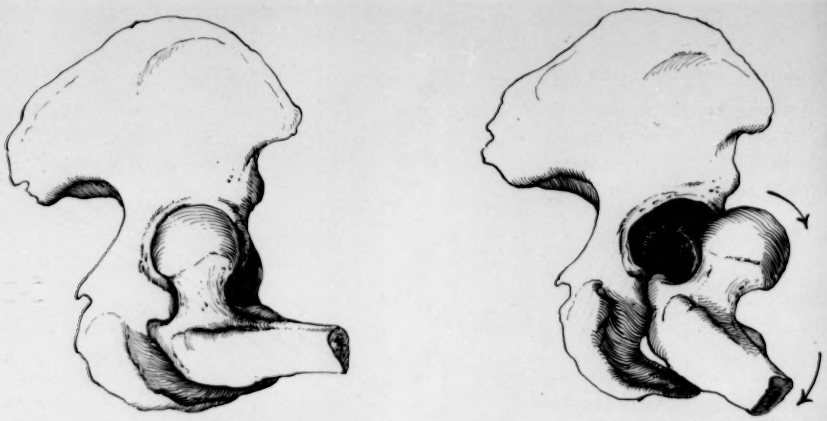

FIG. 2

Shows possible mechanism of anterior dislocation of hip in arthrogryposis. Extension of the femur levers the head forward. The contracted obturator externus acts as a fulcrum.

view of the known effect of pressure on joint development, it may be assumed that this retarded development was due to the combined effects of retarded muscle development and insufficient muscle volume.

Skeletal Deformities of the Club Foot

The skeletal structures of the feet were stained to show the cartilage [3] and were cleared for gross examination [9] (Fig. 5-B). The skeletal elements of the two feet were approximately the same size. The neck of the talus on the club foot showed a more medial angulation than on the normal side, and there was some molding of the head of the talus to fit the new position of the navicular. This is taken as evidence that the deformity had been present for some time. The cuboid was displaced medially by about one half its width, and articulated with the medial corner of the anterior process of the calcaneus. Three normal joint motions and one abnormal motion had taken place. The normal motions were:

1. Plantar flexion at the tibiotalar joint.
2. Inversion at the talocalcaneal joint. (As will be noted, the usually associated movements of the calcaneocuboid and talonavicular joints do not occur.)
3. Cavus or flexion on a transverse axis, taking place through all the joints of the arch of the foot.

The abnormal motion was a hinging medially of the calcaneocuboid joint so that this joint was open laterally. In addition, the cuboid had been displaced medially on the calcaneus by about one half its width, and thus articulated with the medial corner of the anterior process of the calcaneus. Microscopic sections through this joint showed the joint space filled with loose mesenchyme. This had allowed a considerable medial shifting of the entire fore part of the foot through Chopart's joint, and brought the navicular into close contact with the medial malleolus. No metatarsus varus deformity was present in this foot.

Skeletal Structures of the Hip

The position of the hip in 90 degrees of flexion and 90 degrees of external rotation had brought the greater trochanter into close contact with the obturator foramen, and greatly shortened the obturator externus. Instead of the usual anterior version of the

femoral neck, there was posterior version. This could also be described as an external torsion of the shaft of the femur of 20 degrees.

Definition of Arthrogryposis (Myodystrophia Foetalis)

Arthrogryposis can be defined as prenatal muscle dystrophy with deformities caused, first, by imbalance between opposing muscles and, second, by retained foetal positions due to deficient muscle volume. Fibrosis of the muscles makes them resistant to stretch and maintains the deformities.

Theoretical Considerations Regarding Anterior Dislocation of the Hip in Arthrogryposis

A possible mechanism of anterior dislocation of the hip in arthrogryposis is suggested by the relation of the femur and pelvis. It is probably a combination of the retained foetal positions and fibrosis of muscle. With the hip flexed 90 degrees and externally rotated 90 degrees, the greater trochanter lies close to the obturator foramen, shortening the obturator muscle (Fig. 1-D). Extension of the hip at the time of birth could lever the femoral head out of the acetabulum anteriorly, the shortened, fibrosed obturator externus being used as a fulcrum (Fig. 2). The anterior position of the head corresponds with that shown clinically by Badgley in cases of arthrogryposis.

THREE-MONTH FOETUS

The three-month foetus had unilateral club-foot as its only abnormality (Fig. 3-A). Microscopically, the posterior calf group of muscles were abnormal.

In Figure 3-B, the photomicrograph shows both straight and folded muscle fibers. The individual muscle fibers are shown in the sketch. The straight fibers have poorly staining cytoplasm and pyknotic nuclei. In contrast, the folded fiber has normal nuclei and normally staining cytoplasm. Two normal muscle fibers are shown at the right for comparison. It is evident that the straight fibers are dying. They have failed to keep pace with the growth of the skeleton and their relative shortening is evidently the cause of the club-foot deformity. This type of muscle development also occurs in the pig, but in the pig it is the normal type [2]. The abnormal fibers eventually disintegrate, and disappear entirely at about the time of birth. It is reasonable to expect the process in the human to follow the same course. Even in this three-month foetus, the fibers appear moribund.

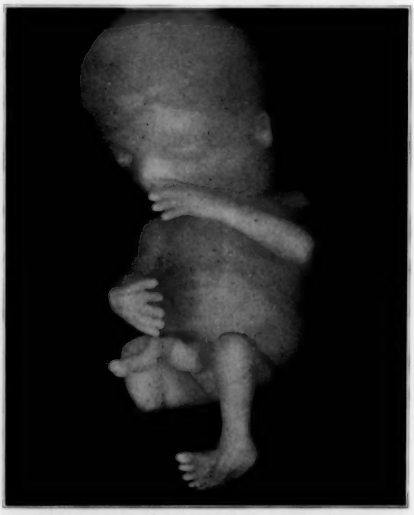

FIG. 3-A

Three-month foetus with unilateral club foot.

We thus have a type of muscle abnormality which could produce deformities during foetal life and then disappear without a trace. This abnormality would be a reasonable cause of so-called idiopathic club-foot.

Gross Anatomy

The crown-rump length of the foetus was 7 centimeters (Fig. 3-A). The estimated foetal age was twelve weeks. The only gross abnormality was club-foot on the left. A dissection, including the brain, eye, spinal cord, and viscera, demonstrated no other gross abnormalities.

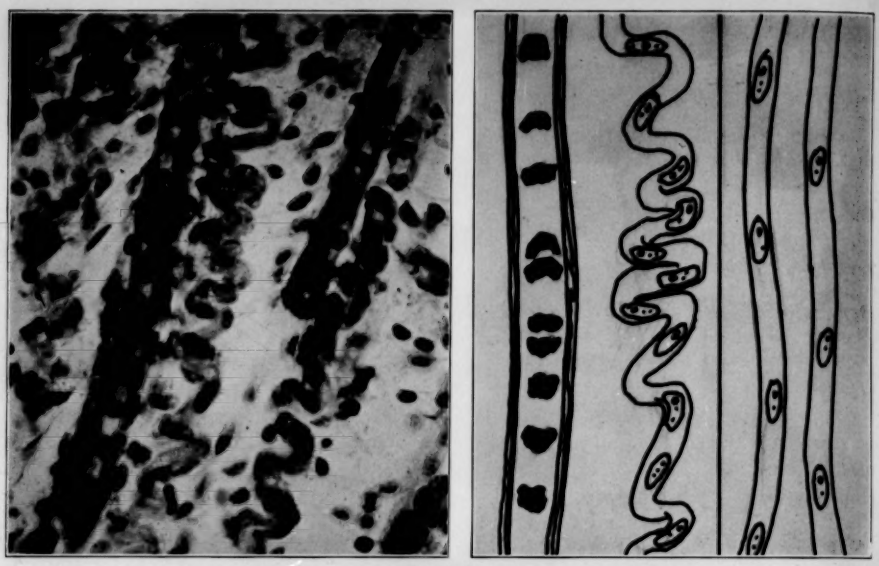

FIG. 3-B

Photomicrograph (× 150) with corresponding drawing. The drawing shows an abnormal fiber with pyknotic nuclei and a folded normal muscle fiber with normal nuclei. Normal fibers from another muscle are shown at the right.

Microscopic Studies

Microscopic examination showed no obvious abnormalities of the viscera, brain, spinal cord, or eyes. Silver staining [18] of peripheral nerves showed no abnormalities of the nerve fibers or of the motor end plates.

Muscles

In the leg having the club foot, all posterior calf muscles showed the presence of many abnormal embryonic muscle fibers (Fig. 3-B). The muscles involved were the gastrocnemius, soleus, posterior tibial, flexor hallucis longus, and flexor digitorum longus. The abnormal fibers constituted about half of the total number and were scattered evenly throughout the affected muscles. They had lost their normal cross striations. The cytoplasm of these fibers was swollen and poorly stained, and all of the nuclei were pyknotic. In the silver stain, normal motor end plates were observed on these abnormal fibers. All of the abnormal fibers were straight as though under tension; the normal fibers beside them were markedly folded and coiled upon themselves. This suggests that muscle fibers actually grow in length and are not merely stretched by the lengthening skeleton. In many other muscles an occasional abnormal fiber was found near the attachment to the bone. If the abnormal fibers were growing at a retarded rate, they would fail to keep pace with the growth of the skeletal structures, and this would result in their being under tension. The tension could then be the deforming force producing the club foot. Multiple sections through limbs and body showed an occasional abnormal fiber near the end of some muscles.

Comparative Embryology of Muscle

Although this type of degeneration of fibers has not been reported for human muscles [6], it is part of the normal process of muscle development in the foetal pig [2]. In the pig, the process apparently ends at about the time of birth, for then the abnormal fibers disintegrate and can no longer be found. The brachiocephalic muscles from a series of normal

foetal pigs from 4.5 to 17 centimeters in crown-rump length were sectioned. After silver staining [18], it was found that those at the 9-centimeter stage corresponded closely to the muscles in this club-foot foetus. A possible explanation is that the degenerating muscle fibers in the pig act as a checkrein on excessive foetal movement and thus prevent damage to the foetal membranes.

Skeletal Deformity

The skeleton of the foot was stained [3] and the foot was cleared for gross study [9] (Fig. 5-A). The skeletal structures of both feet were of the same size and there were no moldings, such as a change in the angle of the neck of the talus, which is frequently described in older foetus with club-foot. The position of the skeletal elements of the foot indicated that three normal joint motions and two abnormal joint motions had taken place. The normal joint motions were:

1. Plantar flexion at the tibiotalar joint.

FIG. 4-A

FIG. 4-B

Roentgenograms from a case of congenital posterior angulation of the tibia. On'y the distal tibial epiphysis appears to be affected. Recovery after three years of growth is shown.

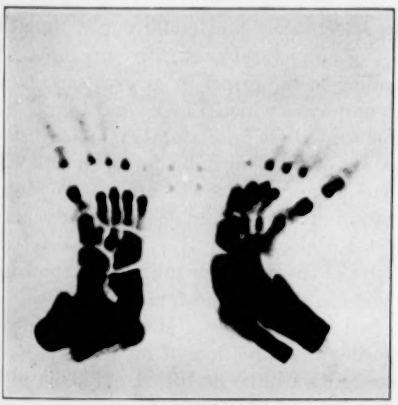

FIG. 5-A

FIG. 5-B

Stained feet of three-month and four-month foetus, showing progressive disruption of calcaneocuboid joint. Normal foot is shown at the left in each illustration for comparison.

2. Inversion at the talocalcaneal joint (the usually associated movements of the calcaneocuboid and the talonavicular joints did not occur).

3. Cavus deformity or flexion of the entire foot on a transverse axis through all the joints of the arch of the foot.

The abnormal motions were:

1. A hinging medially of the calcaneocuboid joint, so that the joint was opened laterally, as opposed to its usual downward and medial gliding motion. This resulted in the stretching of the lateral ligaments, which at this time consist of rather loose mesenchymal tissues. Sections of the joint showed the wedge-shaped space to be full of loose mesenchyme. This motion of the calcaneocuboid joint carried the navicular to the medial side of the head of the talus.

2. The tarsometatarsal joints were all hinged medially, leading to metatarsus varus deformity.

SKELETAL-MUSCLE ABNORMALITIES

Congenital Deformities in which the Muscles May Be an Etiological Factor

In order to place skeletal-muscle abnormalities in their proper relation to other congenital deformities, many more observations will be necessary. In the following paragraphs two congenital deformities are presented as possible examples of cases in which muscle abnormalities might be a cause of the deformity. (This is a purely theoretical discussion and we have no definite evidence that muscle abnormalities cause either of these deformities.)

A deformity to be considered is congenital posterior angulation of the tibia (Figs. 4-A and 4-B). As Heyman and Herndon have pointed out, contracture of the anterior tibial muscles before birth could produce the deformity. After birth, these muscles are easily stretched, and continuing epiphyseal growth corrects the deformity.

FIG. 6

Roentgenogram* of adult untreated club foot. Note the marked medial displacement of the cuboid.

The roentgenograms show that the proximal tibial epiphysis is not affected because the origin of the anterior tibial muscles is distal to this epiphysis. The tarsal sinus offers a bony block to excessive eversion. This is in contrast with the marked inversion in clubfoot. The muscle pull could cause unilateral arrest of epiphyseal growth by pressure. This is similar to the arrest in growth on one side of an epiphysis which Blount and Clarke have demonstrated in unilateral stapling. With cessation of the deforming force, the epiphysis returns to normal growth and the deformity is actually corrected in time. In congenital dislocation of the hip and acetabular dysplasia, there is a similar pattern of muscle and skeletal abnormality. Hart emphasized that one of the important diagnostic signs is contracture of the adductor muscles of the hip at birth, combined with retarded development of the acetabulum and femoral head.

The contracted adductor muscles are stretched by any type of abduction splint. By maintaining the hip in abduction and thus altering the direction of muscle forces, the skeletal deformities return toward normal. Although we have no direct evidence of abnormal skeletal development as an etiological factor in congenital dislocation of the hip and acetabular dysplasia, it should be given definite consideration.

* From the Anatomy Department, University of Wisconsin.

Skeletal Changes in Club-Foot

The skeletal structures of the club feet in the two foetus studied show stages of development of the deformity and indicate a possible cause of recurrence (Figs. 5-A and 5-B). The skeletal elements were stained by means of a cartilage stain [3] and were cleared for observation [9]. The normal foot is shown at the left of each illustration for comparison.

In the three-month foetus, the ligaments of the calcaneocuboid joint have apparently been ruptured and the joint has been rocked open. In the four-month foetus, this process has gone a step farther and the fore part of the foot has been displaced medially at the mid-tarsal joint. The cuboid is in contact with the medial edge of the cuboid facet of the calcaneus. The navicular has been shifted far to the medial side of the head of the talus. The deformity in these feet apparently is not one of retained early foetal position. On the contrary, the skeletal structures appear to have developed normally for a time and then been displaced into the club-foot deformity by abnormal muscle forces.

In Figure 6 we see the roentgenogram of an untreated adult club foot, obtained in the anatomical laboratory. The cuboid has been displaced completely to the medial side of the calcaneus.

It would be interesting to know how far we are able to restore the relationships of the cuboid and calcaneus toward normal in the conservative treatment of club-foot. If the medial shift of the fore part of the foot is not corrected, it may be the cause of recurrent adduction deformity, since it places the invertor muscles in a position of advantage over the evertor muscles.

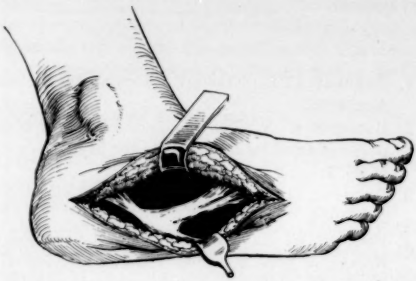

FIG. 7

Drawing of club foot, showing Scherb's abnormal tendinous communication between peronaeus brevis and extensor digitorum brevis.

Possible Causes of Recurrence of Club-Foot

Regardless of the primary cause of club-foot deformity, there are many possible causes of recurrence. These may be related to the primary cause or they may be secondary results.

The muscle in arthrogryposis is markedly fibrosed and its resistance to stretching is well known. Even a slight degree of fibrosis would make the club foot resistant to conservative treatment and tend to cause recurrence with further skeletal growth. Stewart and Garceau and Manning have demonstrated abnormal tendon attachments which could cause recurrence of the deformity.

Scherb has found an abnormal tendinous attachment of the peronaeus brevis to the extensor brevis (Fig. 7). This could reduce the effectiveness of the peronaeus brevis as an evertor and could cause recurrence of the adduction deformity.

Garceau and Manning's clinical observations on the imbalance between the invertor and evertor muscles are very important. They have demonstrated that the establishment of the evertor power by transplantation of the anterior tibial tendon to the base of the fifth metatarsal will prevent recurrence in most cases of club-foot.

CONCLUSIONS

1. The first foetus described probably represents the early stage of arthrogryposis multiplex congenita. There are two apparent causes of deformity in this condition,—first, muscle imbalance due to unequal maturity of opposing muscle groups; and, second, retained foetal positions as the result of insufficient total muscle volume.

2. The only deformity presented by the second foetus is club-foot, apparently caused by abnormal skeletal-muscle development. The muscle abnormality consists of degenerating muscle fibers which fail to keep pace with skeletal growth, the relative shortening of these fibers being the apparent cause of the deformity.

3. In neither foetus does the club-foot deformity seem to be a retained early foetal position. The skeletal structures of the foot apparently developed normally until displaced by abnormal muscle forces.

4. The skeletal structures of the club foot show the early stages of medial displacement of the cuboid upon the calcaneus.

5. It is suggested that the skeletal-muscle factor be investigated in congenital posterior angulation of the tibia, and in congenital dislocation of the hip and acetabular dysplasia.

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DISCUSSION

Dr. Carl E. Badgley, Ann Arbor, Michigan: There is much in this paper I would like to discuss.

First of all, Dr. Bechtol and Dr. Mossman have studied and observed these two congenital deformed feet of the embryos for a number of years. They have presented the anatomical findings. Fundamentally this is a most important paper.

There is a two-sided presentation, however, which may detract from the real merit of this paper: first, the scientific anatomical facts and, second, the correlation of these facts with a possible faulty hypothesis.

The authors have demonstrated abnormality in the muscles of the leg in these two specimens. They

have pointed to the normal appearance of this tissue in pigs, but state that it disappears after birth of the pig. There seems definite evidence in these two specimens that there is an abnormality in the development of the muscle fibers; these fibers in themselves may play a definite part in the retention of the foetal position, and thus may be a causative factor in the development of deformity. To this I agree. I object to correlating this concrete finding to the highly improbable hypothesis of Middleton (of a primary contraction of the gastrocnemius as the cause of a kyphotic tibia), applied to a concept that contraction of the muscles of the anterior compartment of the leg produces posterior tibial bowing. This is hypothetical and unproved. There is no evidence of contracture of the muscles, and to my mind the theory is untenable. The essential feature of the paper is to emphasize the anatomical abnormalities noted, which lose their important significance if applied to an unproved hypothesis.

The geneticists have pointed out the relationship of congenital deformities by hereditary transmission of gene faults, but they have not demonstrated how the gene fault is transmitted or how the deformity is produced. The essayists have demonstrated a fault in muscle development which might well produce the deformity of club-foot, congenital or arthrogrypotic. The primary fault lies in the muscle. The resultant deformity, however, is not intrinsic, but extrinsic, because of the environmental inability of the foot to carry on its normal development due to the constricting bands within the muscle. Inasmuch as this is a normal finding in the pig, according to the authors, and hence an intrinsic mosaic design, it is hinted that in the human it may represent a transmitted gene defect.

The paper is an important contribution to the etiology of congenital deformities.

Dr. George J. Garceau, Indianapolis, Indiana: Like Dr. Badgley, I am in agreement with this paper except for a few little details. This presentation fills a gap in our fundamental knowledge of the deformity of club-foot. It supports the theory that faulty muscle development is a cause of congenital club-foot. Failure of these muscles to lengthen at the same rate as the bones of the skeleton may well be the cause of the inversion of the foot. Failure of development of the normal texture of these muscles may affect their physiology and their ability to stretch and contract normally, and may be a cause of the recurrence of the club-foot deformity.

The medial shift of the cuboid joint, in my opinion, is not the cause of club-foot, but a result of it. This, as far as I know, is the first time that a study of club-foot in an embryo has been presented. We have had suggestions of it in the past, but this is the first time that anyone has had the privilege of studying two foetus in which club-foot was present. I would certainly like to congratulate these two young men on finding two embryos with club feet. I have been looking for one for twenty years and haven't found it yet.

Figure A demonstrates that changes do occur and are present after birth. This is a high-power magnification, which shows degeneration of muscle fibers. Note the clumping of nuclei. I have seen this finding on

Fig. A

High-power magnification (× 275) of photomicrograph of extensor muscle in a patient with congenital club-foot, showing muscle-fiber degeneration, clumped nuclei, and remains of sarcolemma.

numerous occasions. In the severe type of club-foot, pathological changes in the muscles are frequently present after birth.

DR. BECHTOL (closing): Dr. Garceau's findings of abnormalities in skeletal muscles in infants with club-foot are an important contribution. There is no way of knowing at the present time whether his findings are related to one or the other of the foetus described in this paper. Additional microscopic material will be necessary before such conclusions can be reached. Only in arthrogryposis are the microscopic changes associated with muscle abnormalities well known. Dr. Badgley has correctly stressed the importance of carefully differentiating between facts and theoretical considerations. The facts available in the entire field of congenital abnormalities at the present time are meager, and emphasize the need for further careful study of both prenatal and postnatal specimens of congenital anomalies. Although careful studies of the central nervous system and the skeletal system have been pursued in the past, the possibility that a muscle abnormality could be present has been largely overlooked.

If one considers the complexity of foetal development, it is probable that any one of a number of factors might be abnormal at various stages of development and lead to deformities which are indistinguishable at the time of birth. The findings in the foetus described present the possibility that prenatal muscle dystrophy may be the cause of congenital deformity. There are probably several causes of club-foot, and nothing could be more incorrect than to conclude that the muscle dystrophies presented in this paper are the only cause.

SPURS OF THE CALCANEUS IN STRÜMPELL-MARIE DISEASE

REPORT OF FIFTEEN CASES

BY JOE B. DAVIS, M.D., AND HARRY C. BLAIR, M.D., PORTLAND, OREGON

Spurs on the plantar surface of the calcaneus are often seen in young adults. Costa called attention to their occurrence in rheumatic disease and described them accurately. The literature contains numerous other reports of periosteal spur formation of the calcaneus with rheumatic disease, and of spur formation of the calcaneus occurring in association with the various general toxaemias. However, no reference has been found to the association of either calcaneal spurs or calcaneal periostitis with Strümpell-Marie disease.

The authors have seen three patients who had acute periostitis of the calcaneus during the acute phase of Strümpell-Marie disease, and twelve other patients who had mature spurs of the calcaneus during the quiescent stage. As referred to here, Strümpell-Marie disease is the entity manifested by sclerosis of the sacro-iliac joint, obliteration of the costovertebral joints, and calcium deposits in the periarticular and perivertebral ligamentous apparatus, which give the appearance commonly referred to as "bamboo spine".

Acutely Painful Heels

Three patients had acute bilateral heel pain and, in addition, pain along the entire back, limitation of chest motion, malaise, and lassitude. Two patients had had these symptoms for seven months, and the third for nine months. All were eighteen years old.

Roentgen studies of each patient showed the sclerotic sacro-iliac joints characteristic of acute Strümpell-Marie disease; the heels appeared normal. In each case a diagnosis was made of acute Strümpell-Marie disease, associated with periostitis of the calcaneus.

Roentgenotherapy * was administered to these patients, the first two treatments being given on alternate days. After an interval of six weeks, the procedure was repeated, each patient receiving a total of four treatments. Treatment was limited to the cervicothoracic, the thoracolumbar, and the lumbosacral areas. The area of irradiation on each side of the spine was 4 centimeters wide, and the area at the sacrum was 15 centimeters wide. Each treatment consisted of 140 roentgens (5 milliamperes, 3 millimeters of aluminum, and 140 kilovolts).

All three patients were relieved of pain in the heels as well as in the back. At the time of this report, one patient has been asymptomatic for two years and one for one and one-half years. The third had a recurrence of the heel pain two years after roentgenotherapy. Roentgenograms showed early spur formation of the calcaneus.

Chronically Painful Heels

Twelve patients complained of dull pain in the heels, aggravated by weight-bearing and relieved by rest. The duration of the pain had varied from one to three years. One patient had pain only in the heel of a foot with traumatic flat-foot deformity. The others had bilateral heel pain. All patients denied ever having had acute pain in the heels; however, it was felt that some may have had an acute episode of heel pain. These patients had no other complaints. Their ages ranged from twenty-two to thirty years.

Roentgen studies of each of the twelve patients showed advanced sclerosis of the sacro-iliac joints and calcaneal spurs having the conformation and consistency of normal bone. In each case a diagnosis was made of "established" spurs of the calcaneus, associated with quiescent Strümpell-Marie disease.

Because three patients had been relieved of painful periostitis of the calcaneus and acute Strümpell-Marie disease by roentgenotherapy to the spine, four of the patients with established spurs and quiescent Strümpell-Marie disease were treated in a like manner. As far as could be determined, there was no change in their heel pain. It was, therefore, deemed advisable to direct the roentgenotherapy to the spurs as recommended by Liberson and Pokorny, but this procedure was of no benefit.

In an attempt to transfer weight-bearing from the spurs to some other surface of the heels, the shoes of these twelve patients were fitted with metal arch supports, as described by Whitman. Supination of the heels by this means relieved the foot symptoms of nine patients. In our experience, elevation of the heels with pads of rubber or other material has not relieved the pain.

The patient who had the traumatic flat-foot deformity (Case 10) was also relieved of his heel pain by the Whitman arch support, but the support caused so much static disturbance in the foot that it had to be discarded. The operation for flat-foot described by Miller was then carried out, and complete relief of the pain was obtained.

Whitman arch supports proved ineffective for two patients (Cases 11 and 12), but subsequent resection of their spurs relieved the heel pain of both. In each case, the authors made a U-shaped incision around the posterior surface of the heel and retracted the skin and the plantar subcutaneous tissue forward. The anterior tubercle of the calcaneus with its accompanying spur was then removed. The amount of bone removed depended upon the space required to prevent impingement of the subserous bursa.

COMMENT

The authors have observed that men between eighteen and thirty years of age, who present symptoms and signs of calcaneal periostitis or spurs of the calcaneus, invariably

* Given by S. E. Rees, M.D., and G. B. Nichols, M.D.

also have changes of the lumbosacral spine and of the sacro-iliac joints characteristic of Strümpell-Marie disease. Jacobs made similar observations.

At this time we cannot give an accurate description of the pathogenesis of the calcaneal changes associated with this disease. Nevertheless, the course of one patient (Case 3) confirms our opinion that the acute calcaneal periostitis observed in the acute phase of Strümpell-Marie disease progresses to the mature spur formation seen during the quiescent stage. Furthermore, we feel that the spur formation at the attachment of the plantar fascia to the anterior portion of the tubercle of the calcaneus is the same as the bony proliferation that occurs in other locations in Strümpell-Marie disease.

Roentgenotherapy, which is an established treatment for acute Strümpell-Marie disease [1, 8, 9, 10], relieves the pain of acute calcaneal periostitis and in some cases may prevent spur formation.

The dull, chronic heel pain typical of mature spurs is not relieved by roentgenotherapy. This pain is caused by impingement of the subserous bursa between the spur and the sole of the foot. To be effective, treatment must include supination of the calcaneus to enlarge the plantar space and thus prevent impingement of the subserous bursa [3, 11, 12]. This treatment is based on the principle that supination of the hind part of the foot is associated with dorsiflexion of the calcaneus, and that pronation of the foot is associated with plantar flexion of the hind part of the foot and its calcaneus.

Supination can be accomplished by a simple metal arch support. However, as the authors' experience in Cases 10, 11, and 12 has proved, not every patient is relieved of pain by conservative means. When relief is not obtained by these measures, surgical intervention is necessary to increase the space for the subserous bursa.

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FURTHER EXPERIENCE IN THE MANAGEMENT OF OSTEITIS CONDENSANS ILII *

BY FRANK L. SHIPP, M.D., AND G. EDMUND HAGGART, M.D., BOSTON, MASSACHUSETTS

From the Department of Orthopedic Surgery, The Lahey Clinic, Boston

The term osteitis condensans ilii is used to describe a disturbance of the normal architecture of the ilium, alongside the sacro-iliac joint. Roentgenograms disclose increased condensation in the auricular portion of the ilium, in the absence of any corresponding change in the sacro-iliac joint or in the contiguous sacrum.

The roentgenographic appearance of osteitis condensans ilii was first described by Sicard, Gally, and Haguenau in 1926. Two years later, Bársony and Polgár recognized that the process was sclerotic in nature; in 1932, Berent suggested that it was a complication of pregnancy. It was not until 1944 that Hare and Haggart reported a series of female patients with this condition, some of whom were nulliparous; these authors were the first to describe the associated clinical manifestations. It was their belief that the condition might represent a disturbance of circulation. Several of their patients gave a history of trauma, in some instances related to childbirth, which they considered a possible cause for alteration in the blood supply of the inferior portion of the ilium, adjacent to the sacro-iliac joint.

ANATOMY

The sacro-iliac articulation is an amphiarthrosis, the auricular surfaces of the sacrum and ilium being separated by thin plates of cartilage. In the young adult, these cartilaginous plates are intimately blended with each other. In later years they become separated by fluid with the formation of a joint space, thus converting the articulation into a diarthrosis.

According to Grant, although the motion involved is minimal, the sacrum tends to rotate forward about a fulcrum situated in the vicinity of the second sacral segment (Fig. 1). This tendency results from the weight of the superimposed vertebral column in the erect position. The ligaments of the sacro-iliac joint are so situated that they are disposed to resist such rotation. However, the sacrum does not form a keystone in the posterior arch of the pelvis. On the contrary, its articular surfaces lie farther apart anteriorly than posteriorly. For that reason, in the weight-bearing position, the bone tends to be displaced forward into the pelvis. The interosseous and posterior sacro-iliac ligaments resist this tendency by becoming taut, forcing the ilia more closely together. Better apposition is thus afforded the interlocking ridge and furrow which are found in the articular surfaces of the ilium and the sacrum, respectively (Fig. 2).

ETIOLOGY

The efficiency of this locking mechanism is impaired in some females in whom the sacro-iliac joint lies in the sagittal rather than in the more normal oblique plane. A further factor interfering with the stability of the articulation is added during pregnancy, when relaxation of the sacro-iliac ligament and other pelvic ligaments occurs, with the result that increased strain falls upon the articular surfaces of the bones involved.

In either event, the auricular portion of the ilium resists the thrust of the sacrum as the latter rotates forward about its fulcrum. As the strain persists and increases, more and more of the ilium becomes subjected to abnormal pressure. From personal observations,

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 15, 1950.

the authors believe that continued pressure upon the articular surface of the ilium is the cause of the increased condensation seen on roentgenographic examination. That these changes can be reversed in certain cases by correction of the postural defects associated with them has been demonstrated by serial films. Furthermore, many patients with persistent roentgenographic findings have been relieved of their symptoms by the conservative measures to be described.

PATHOLOGICAL FINDINGS

In 1936, Rendich and Shapiro reported the microscopic appearance of iliac bone removed from a patient with osteitis condensans ilii. They remarked that osteoblasts

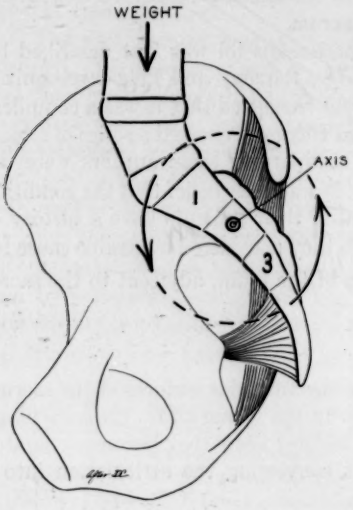

FIG. 1

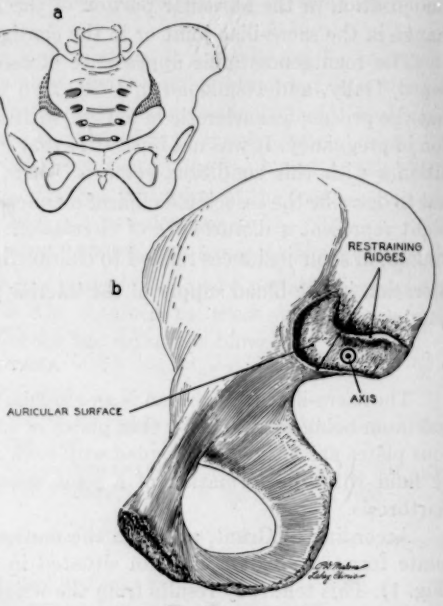

FIG. 2

Fig. 1: Drawing of rotatory force affecting sacrum.
Fig. 2: Sacral articular surface of ilium.

and osteoclasts were conspicuously absent and that the lacunae were obliterated by marked condensation of the osseous tissue.

The authors' limited experience has been somewhat at variance with these findings, although the discrepancies may represent the difference between two phases of the same process (Fig. 3). It was found that, although the trabeculations were greatly increased in density, the lacunae were still readily discernible. Scattered islands of cartilage were observed at a considerable distance from the joint surface. The bone marrow showed focal areas of fibrosis against a normal background. There was evidence of osteoblastic activity in excess of the normal in the form of clumps of osteoblasts and occasional osteoclasts. These findings were thought to represent a low-grade, non-specific ischaemic process (Fig. 4).

SYMPTOMS

Chronic low-back pain was the chief complaint. The character of this pain served to distinguish it from either sacro-iliac arthritis or radicular irritation. The pain was described as radiating to one or both buttocks, never into the sciatic distribution. There was no aggravation of symptoms as a result of coughing or straining, but symptoms were caused or aggravated by activity. Relief always was obtained with rest. Significantly,

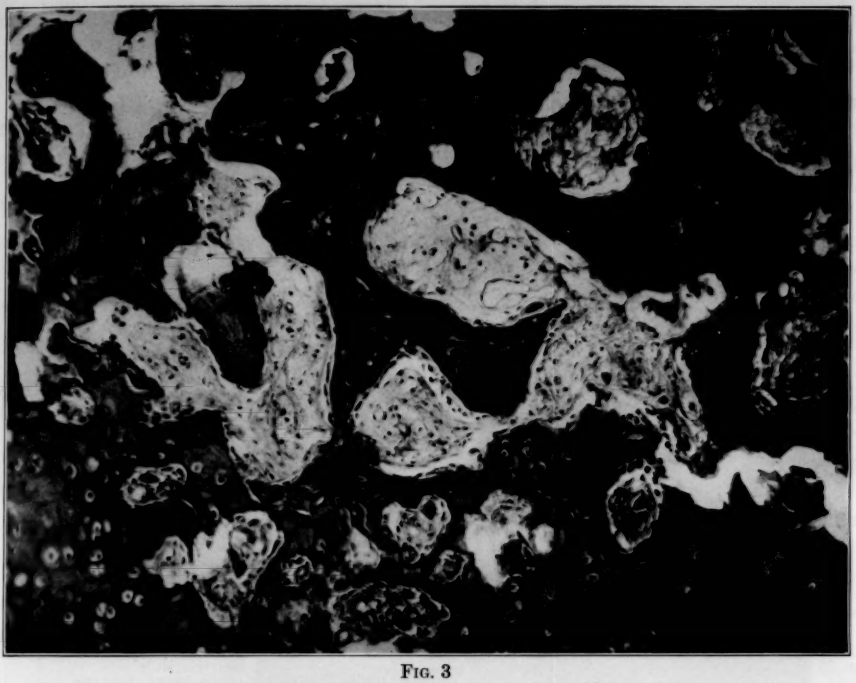

FIG. 3

Microscopic section (× 120) from case of osteitis condensans ilii.

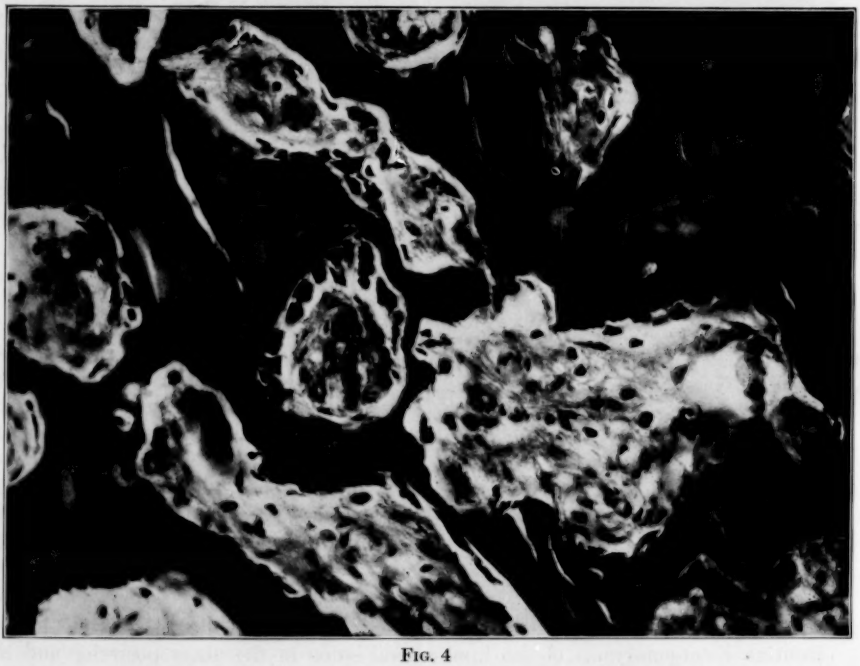

FIG. 4

Microscopic section (× 320) from case of osteitis condensans ilii.

there was no night pain. The complaint was seldom incapacitating, but it usually increased slowly in severity and became more or less continuous.

Many of the patients stated that their pain had occurred during the final trimester of pregnancy or immediately after delivery. Furthermore, they noted recurrence or exaggeration of their symptoms during subsequent pregnancies. In other patients, symptoms appeared to follow a rapid gain in weight, excessive physical fatigue, or other debilitating factors. There was seldom any history of severe trauma involving the back.

All of the authors' patients were white women, the eldest forty-four years and the youngest nineteen years of age; the average age was thirty-two years. Symptoms had been present before diagnosis for periods ranging from four months to eighteen years, the average being four years.

PHYSICAL AND LABORATORY FINDINGS

Physical examination was usually remarkable only for an increase in the normal lumbar lordosis. In the severe cases, as with chronic lumbosacral strain, spasm of the erector muscles was evident. Tests for sacro-iliac joint disease, including alternate compression and separation of the iliac crests and straight-leg-raising, were uniformly negative. The most consistent finding was inadequate musculature, often associated with moderate obesity. The laboratory findings were not remarkable.

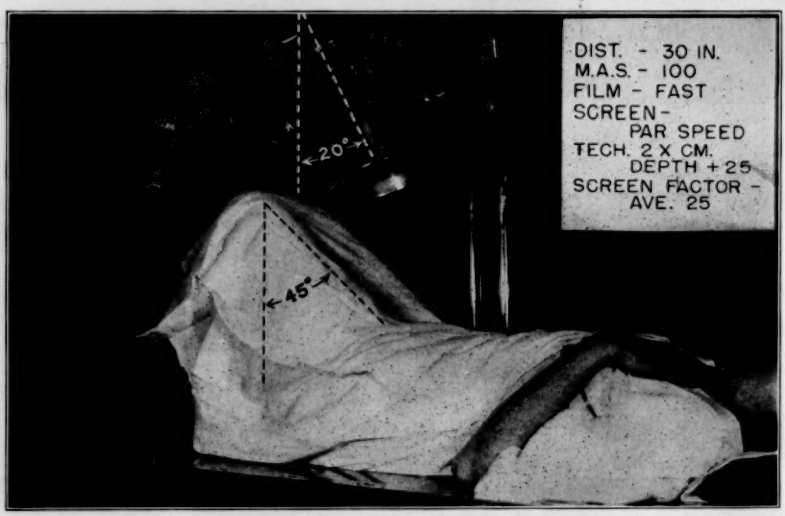

FIG. 5

Roentgenographic technique employed for flat sacral projection.

Originally, we erred by including in this category some patients who subsequently were found to show Marie-Strümpell arthritis. In this latter group, some feature of sacro-iliac disease could usually be found on further physical and roentgenographic examination. In every such patient, moreover, the blood sedimentation rate at the time of the initial examination was found to be elevated above the normal limit of 20 millimeters per hour (Westergren).

ROENTGENOGRAPHIC FINDINGS

Routine roentgenograms of the lumbosacral spine in the anteroposterior and the lateral projections do not afford satisfactory visualization of the sacro-iliac articulations.

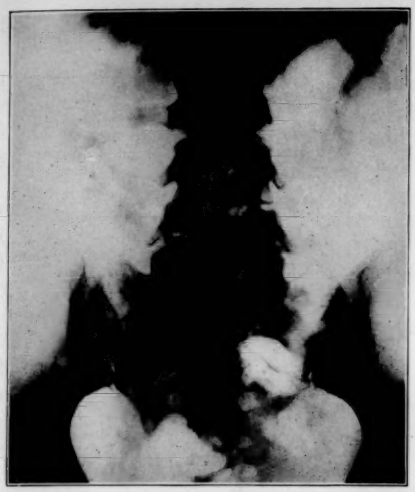

FIG. 6
Osteitis condensans ilii.

FIG. 7
Marie-Strümpell arthritis.

The most satisfactory film of this area is the flat sacral projection (Fig. 5). This film is now included in the standard lumbosacral series.

Osteitis condensans ilii is found in the female, where the sacrum tends to lie in a more horizontal plane than in the male. The auricular portion of the ilium is most commonly involved. This portion lies behind the anterior margin of the joint, so that condensation therein may give the false impression of involvement of the sacrum or even of the sacro-iliac joint.

From stereoscopic flat sacral films, it was evident that both the sacro-iliac joint and the adjacent sacrum were normal in appearance. Dense sclerosis was seen in the auricular portion and sometimes in that part of the ilium alongside the sacro-iliac joint (Fig. 6). In this area the normal bony trabeculations were obscured; usually there was no sharp line of definition between normal and abnormal bone. Finally, it became evident that the roentgenographic appearance was not indicative of the severity of symptoms.

DIFFERENTIAL DIAGNOSIS

This condition is most often confused with sacro-iliac arthritis, especially that of the Marie-Strümpell type (Fig. 7). This latter occurs more commonly in the male, while osteitis condensans ilii, from our experience, occurs only in the female. Physical examination will usually serve to differentiate the two conditions. With minimal involvement of the sacro-iliac joint in Marie-Strümpell arthritis, sacro-iliac tests are commonly positive, while in osteitis condensans ilii such tests are consistently negative. Even in the absence of such physical findings, an elevated sedimentation rate should make one suspicious of arthritis. On roentgenograms, roughening and apparent

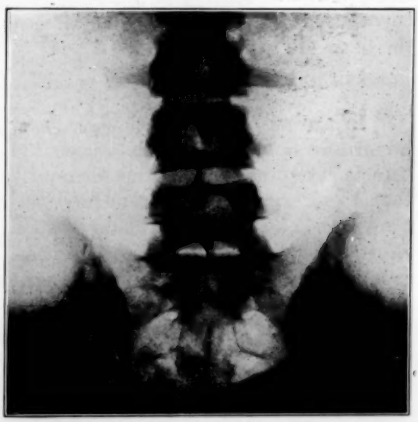

FIG. 8
Sacro-iliac epiphysitis.

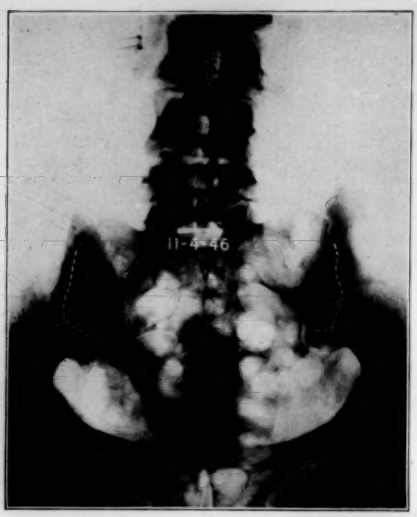

FIG. 9-A

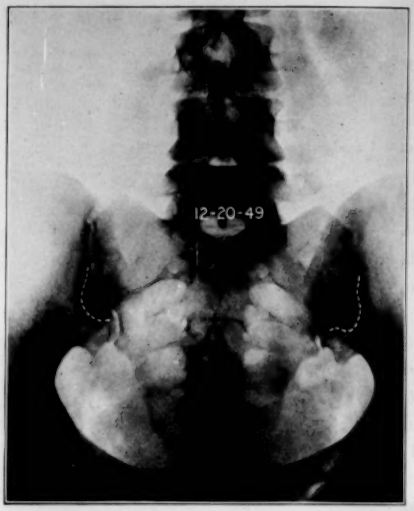

FIG. 9-B

Roentgenograms show regression of sclerosis after conservative treatment in case of osteitis condensans ilii.

widening of the joint itself can be seen early in Marie-Strümpell arthritis.

Sacro-iliac epiphysitis may occasionally be seen in the young adult (Fig. 8). The roentgenographic appearance may simulate that in Marie-Strümpell arthritis, but it will serve to distinguish this condition from osteitis condensans ilii. As in the latter, the sedimentation rate is usually normal.

The low-back syndrome associated with asymmetry of the lumbosacral facets is readily distinguished from the foregoing conditions. Recurrent attacks of acute low-back pain, usually without sciatic radiation, may follow minor strains or unguarded motions. The attacks are characterized by marked spasm of the erector muscles and often by a list. Localized tenderness is present over the lumbosacral region. Sacro-iliac tests are usually negative. Roentgenograms reveal the anomalous arrangement of the lumbosacral articulations, while the sacro-iliac areas appear within normal limits.

Osteitis deformans (Paget's disease) and degenerative arthritis may be excluded on the basis of age incidence.

TREATMENT

In the majority of patients, conservative treatment has been employed. The most important single measure has been the correction, where possible, of obvious postural defects. This was accomplished primarily through training in active muscle exercises under the supervision of a competent physical therapist. This training was continued until such time as the correct posture could be maintained by the patient without conscious muscular effort,—usually six months to one year. Postural training was further supplemented by reduction of excessive weight, by increased rest and the use of a bed board, and occasionally by an adequate corset.

Two patients, both young married women of small stature, had persistent symptoms despite adequate conservative treatment; fusion of the sacro-iliac joints was required. Complete relief of symptoms was obtained in each instance. Gross and microscopic examination of the bone removed disclosed findings consistent with those described earlier. Bacteriological studies, employing both aerobic and anaerobic techniques, gave negative results.

ANALYSIS OF RESULTS

One hundred patients with osteitis condensans ilii were selected for study from a series extending back to 1943. Preliminary investigation revealed that, among those patients so classified between 1943 and 1946, twenty-nine were found subsequently to show Marie-Strümpell arthritis. Since 1946, however, no amendments of diagnosis have been necessary. Thus, to obtain adequate case material, a total of 129 cases have been reviewed, in 100 of which the diagnosis has remained osteitis condensans ilii. The average follow-up period has extended over seventeen months.

All patients studied were adult white females. Seventy-eight had borne children; of these, forty-eight dated their symptoms from pregnancy. Complicating structural defects were found in twenty-three patients. Sixty-four were overweight.

The results were classified primarily on the basis of symptomatic relief, but also on the correction of positive physical and roentgenographic findings. Of the 100 cases of osteitis condensans ilii, complete relief of pain was obtained in thirty-one patients, including two for whom surgical intervention was required; thirty-eight reported that, while some discomfort persisted, their major complaint had been relieved. Twenty-three patients noted diminution of their symptoms, although moderate low-back pain still occurred periodically; eight patients obtained little or no benefit from treatment. The most significant finding was that, in six of 100 patients, serial roentgenograms disclosed that the degree of sclerosis had actually diminished during treatment (Figs. 9-A and 9-B).

SUMMARY AND CONCLUSIONS

1. Osteitis condensans ilii represents an alteration in the normal bony architecture of that portion of the ilium alongside the sacro-iliac joint. The authors' observations thus far suggest that this occurs as the result of mechanical strain affecting an amphiarthrodial joint. Further investigation regarding the etiology and the pathology of this condition is under way.

2. A careful differential diagnosis must be made between osteitis condensans ilii and Marie-Strümpell arthritis, with which it has been confused in the past. Contrary to the authors' own original impressions, sacro-iliac tests are seldom positive in osteitis condensans ilii, while the blood sedimentation rate is usually within normal limits.

3. Again in contrast to the experience of earlier workers, the authors have demonstrated roentgenographically in six patients that this process is reversible.

4. Of 100 patients reviewed, eight showed no response to treatment and twenty-three were somewhat improved; in sixty-seven patients conservative treatment afforded either complete relief or marked amelioration of symptoms. Surgical intervention was necessary in only two instances.

NOTE: The authors wish to express their gratitude to Robert M. Green, M.D., for his advice regarding the anatomical aspects of this problem, and to Shields Warren, M.D., and William A. Meissner, M.D., for their suggestions and assistance in preparing the pathological reports and photomicrographs.

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MARIE-STRÜMPELL ARTHRITIS

Follow-up Study of Roentgenographic, Physical, and Orthopaedic Therapy *

BY LENOX D. BAKER, M.D., R. W. COONRAD,† M.D., ROBERT J. REEVES, M.D., AND W. A. HOYT, JR., † M.D., DURHAM, NORTH CAROLINA

From the Orthopaedic Division, Department of Surgery, and the Department of Roentgenology, Duke University School of Medicine, Durham

Smyth, Freyberg, and Lampe, in the summary of their report on the treatment of arthritis of the spine with roentgenotherapy, stated: "The results were excellent in the patients with early disease, in whom roentgenograms revealed abnormalities only in the sacroiliac joint; in this group 92 per cent. showed significant, sustained, subjective and objective improvement, and some were completely relieved of all clinical evidence of the disease. In the later stages, after spinal ligamentous calcification had occurred, we were surprised to find that a high percentage showed significant reduction in pain and stiffness and in some cases objective improvement." They further stated: "We consider roentgen therapy the best method of controlling the symptoms of rheumatoid arthritis of the spine; whether the benefit is entirely symptomatic relief or whether the course of the disease is favorably affected will need to be determined by further investigation".

In previous publications, two of the authors [1–4,10] have described apparatus and have reported early results in the treatment of rhizomelic spondylitis by the roentgen ray, combined with physical therapy and orthopaedic measures. The purpose of this paper is to report late results of the combined therapy.

The history of the disease and its signs and symptoms need no discussion in this paper. Those interested in such aspects of the disease are referred to Herrick and Tyson for a classical presentation of the medical viewpoint; to Forestier for an excellent description of the roentgenographic changes; to Swaim for the principles of the orthopaedic treatment; and to the authors' previous publications for details of the combined therapy.

Little is known as to the etiology of the disease. Its exact relationship to the other arthritides has not been established. It is usually classified as a form of rheumatoid arthritis, but the accuracy of such a classification is questionable. In addition to the clinical variations, there appear to be basic differences in the two diseases. Rheumatoid arthritis is seen in both sexes with the same relative frequency, whereas Marie-Strümpell arthritis is common to the male, but is seen rarely in the female. Rheumatoid arthritis affects primarily the peripheral joints, the spine frequently being free of involvement. Marie-Strümpell arthritis, on the other hand, is seen primarily in the spine with only occasional involvement of the joints of the extremities; when the peripheral joints are involved, the poor response to roentgenotherapy makes one question the presence of a mixed arthritis in this group of patients. The roentgenographic changes seen in Marie-Strümpell arthritis consist of increased density of the subchondral bone with mottling and loss of trabeculation. In rheumatoid arthritis one sees atrophy of the subchondral bone. Acute onsets, remissions, and exacerbations are common in rheumatoid arthritis. Marie-Strümpell arthritis has an insidious onset and progresses slowly, with little variation in the severity of the symptoms.

Recent laboratory studies have shown further differences in these two diseases. Rose and his associates, in a study of the differential agglutination of normal and sensitized sheep erythrocytes, have shown that the sera of patients with rheumatoid arthritis will

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 15, 1950.

† Aided by Fellowships from the National Foundation for Infantile Paralysis, Inc., New York, N. Y.

agglutinate sensitized sheep erythrocytes to a serum dilution of 1 to 2,048. A similar study with the sera of patients with Marie-Strümpell arthritis demonstrated what were considered to be negative tests.

Davison, Koets, and Kuzell found increased urinary excretion of 17-ketosteroids in both male and female patients with ankylosing spondylitis. A similar increase was not found in patients with rheumatoid arthritis. Mowbray, Latner, and Middlemiss did not confirm Davison's findings; however, they did demonstrate a striking difference in the serum colloidal-gold reaction in the two diseases, the reaction being predominantly positive in the rheumatoid group and negative in the spondylitis group.

Goldfain noted a high percentage of positive skin reactions, agglutinations, and opsonic index tests for brucellosis in Marie-Strümpell arthritis. Coonrad did skin tests with brucellergin on sixty-six consecutive patients with Marie-Strümpell arthritis. As a control, the same test was made on seventy-seven consecutive patients with no history of back or joint symptoms, and on thirteen consecutive patients with rheumatoid arthritis. Of the sixty-six patients with Marie-Strümpell arthritis, thirty-seven (56 per cent.) showed positive reactions. Of the seventy-seven controls, seventeen (22 per cent.) showed positive reactions. Of the thirteen patients with atrophic arthritis, only one (7.7 per cent.) showed a positive reaction. Coonrad feels that the differences in the various laboratory findings do not throw light on the etiology of the two diseases, but that they do indicate the possibility of altered sensitivities in both diseases. Thus far, these sensitivities have been different in each disease. In addition to the clinical, roentgenographic, and laboratory variations, the two diseases differ markedly in their response to roentgenotherapy.

During the past nine years, 568 patients with Marie-Strümpell arthritis have been treated at the Duke Hospital with roentgenotherapy, combined with a physical-rehabilitation program consisting of physical therapy, active exercises, braces, and vocational training. The roentgenotherapy in most instances has consisted of 150 roentgens (200 kilovolts), given over areas measuring 5 by 15 centimeters until the entire spine or the area to be treated has been covered.

Of the 568 patients, 347 were treated four or more years ago. During the past six months, 100 patients of this latter group have returned to our Clinic for orthopaedic examination, laboratory tests, and roentgenographic studies. The recent studies of these 100 patients will serve as the nucleus of this report. In an effort to evaluate the results of therapy, the patients were classified categorically into four groups,—namely (1) mild, (2) moderately advanced, (3) advanced, and (4) far advanced. The classifications were based chiefly on the roentgenographic changes and on the clinical findings. After careful consideration, it was felt impossible to classify the patients according to the duration of their symptoms, as this factor appeared to have very little relationship to the other findings or to the response to therapy.

Of the 100 patients, ninety-seven were white and three were negro; eighty-four were males, sixteen were females. Twenty-one were in the third decade of life, forty-six were in the fourth decade, twenty-two were in the fifth decade, and eleven were in the sixth decade. Symptoms had been present from five to forty years with the following distribution of duration: five years or under, four; six to ten years, fifty-three; eleven to fifteen years, twenty-six; sixteen to twenty years, twelve; over twenty years, five. The time which had elapsed since the initial therapy was as follows: eight years or more, thirteen; seven years, twenty; six years, thirty; five years, twenty-five; and four years, twelve.

Four factors were taken into consideration in evaluating the results: First was the patient's general well-being. (This factor is difficult to evaluate statistically, but there was definite and in most instances dramatic improvement.) The other factors considered were pain, range of motion, and roentgenographic changes. Twenty patients were classified as having mild changes (Table I).

Twenty-seven were classified as having moderately advanced changes. Fourteen had

FIG. 1-A

FIG. 1-B

Composite photographs showing range of motion before and after therapy. The increase in flexion and extension was demonstrable at the end of seventy-two hours, after the patient had received a total of 450 r over a period of three days. He maintained this range of motion, as shown by examination, five and one-half years after treatment. Improvement in the range of motion, as demonstrated by this patient, is not usually seen. A better example of what can be anticipated is shown in Figs. 2-A and 2-B.

FIG. 2-A

FIG. 2-B

Composite photographs showing range of motion in a patient with moderately advanced roentgenographic changes. The range of motion was obtained within ninety-six hours after roentgenotherapy, and it was maintained at the end of six years. Note that there has been very little increase in the range of flexion, but a satisfactory increase in extension. This is desirable, as it is usually associated with increased motion in the thoracic cage and an increase in vital capacity.

TABLE I

RESULTS IN MARIE-STRÜMPELL ARTHRITIS

Results		Mild Changes	Moderately Advanced Changes	Advanced Changes	Far Advanced Changes	Total Cases
Relief of Pain	Good	15	22	21	16	74
	Fair	3*	3†	4	4	14
	Poor	2	2	7	1	12
	Total	20	27	32	21	100
Range of Motion	Normal‡	10	10	0	0	20
	Increased	7	14	12	0	33
	Decreased	3	3	18	0	24
	Unchanged	0	0	2	21**	23
	Total	20	27	32	21	100
X-Ray Changes	Decreased	4	11	7	3	25
	Unchanged	12	12	11	15	50
	Increased	3	4	14	3	24
	Total	19††	27	32	21	99‡‡

* One had relief for 7 or 8 years and was happy with the result; the other 2 showed general improvement, but the disease advanced and pain continued.

† Partial relief of pain with satisfactory general improvement.

‡ Normal before and after therapy.

** Appreciable correction of deformity in 16.

†† Recent roentgenographic studies showed clearing of process with improvement in texture of bone in 4 and no further advance of the disease in 12; 3 showed further ossification, either about the sacro-iliac joints or about the vertebral bodies.

‡‡ One patient had no x-ray changes before or after therapy. (Treated on basis of history with relief of pain.)

an increased range of motion following therapy (Figs. 1-A, 1-B, 2-A, and 2-B). Roentgenograms showed a clearing of the process in eleven of this group (Figs. 3-A, 3-B, and 3-C); twelve showed no further advance or change; four showed further ossification. Of these four, two had only one series of therapy, consisting of a total of 450 r; one had a total of 1,350 r. However, of the eleven patients whose process showed clearing by roentgenograms, two had only one series of 450 r, two had three series totaling 900 r, and one had a total of 1,350 r.

The lack of correlation between the amount of therapy given and the late results, both as to symptoms, motion, and roentgenographic changes, has been consistent throughout this study (Table II). We have no explanation for it. The therapy has been repeated only if indicated by pain. There has been no satisfactory way to anticipate which patients will require additional therapy after initial treatment or after any subsequent treatment.

There were thirty-two patients in the group with advanced changes. Of the seven classified as having a poor result, one was discharged against advice; he had a mixed type of arthritis which was improved at the time of discharge, but advanced to complete ankylosis of the spine and hips. One patient had relief of pain for eight months, after which the pain returned and there was further ossification. One had only one series of therapy; nausea developed and he refused further treatment. Seven patients in the group with advanced changes showed some clearing of the disease by roentgenograms with better bony texture about the sacro-iliac joints.

Twenty-one patients with roentgenographic evidence of ankylosis of the spine were

classified as having far advanced changes. Of this group, sixteen had complete or almost complete relief of pain following therapy; four had fair relief (two with complete relief for a year or more); one had no relief of pain. It was possible to materially improve the posture in sixteen of the twenty-one patients of this group, in whom the roentgenograms showed what appeared to be ankylosis of the spine.

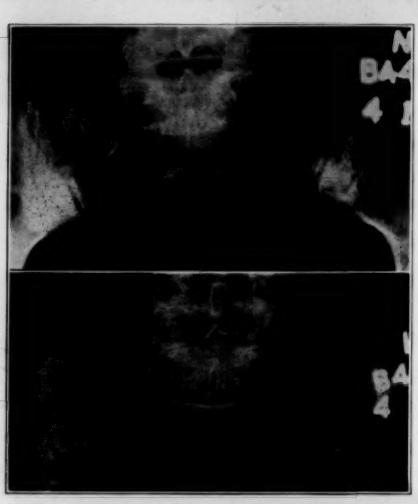

FIG. 3-A

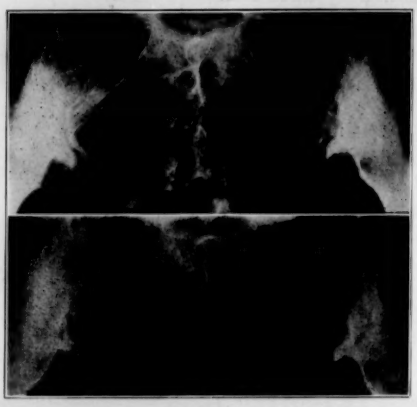

FIG. 3-B

FIG. 3-C

Fig. 3-A: Upper film shows increased density about both sacro-iliac joints. Lower film shows clearing and retrabeculation, five and one-half years after therapy.

Fig. 3-B: More advanced changes with increased density and narrowing of the sacro-iliac joints. Lower film shows changes at the end of six years following therapy. Narrowing of the joint space is still present, but there has been satisfactory retrabeculation.

Fig. 3-C: Left view shows increased density about lower pole and iliac side of the sacro-iliac joint, unilateral in nature. The opaque shadow is a catheter, as this film was taken from a flat plate made for a pyelogram. The right view was taken six and one-half years later, following one series of roentgenotherapy of 450 r.

The changes in these roentgenograms are not what are usually seen following roentgenotherapy, but represent what is described in this paper as clearing of the process following x-ray. Of forty-one patients having mild and moderately advanced changes, only ten showed such improvement.

In spite of this improvement in posture, there was no definite increase in the range of motion.

Of the sixteen females included in this study, six showed roentgenographic changes in keeping with what has been described as osteitis condensans ilii. These patients presented symptoms consistent with what is seen in Marie-Strümpell arthritis. All six responded satisfactorily to roentgenotherapy, as have twelve additional patients treated during the past five years.

TABLE II

RESULTS OF ROENTGENOTHERAPY

Results		Amount of Therapy and Total Units				Total Cases
		One Series 300–450 r	Two Series 600–900 r	Three Series 900–1,200 r	Four Series 1,200–1,800	
Pain	Good	25	24	18	7	74
	Fair	6	5	2	1	14
	Poor	4	5	2	1	12
	Total	35	34	22	9	100
Motion	Normal *	7	8	2	3	20
	Increased	11	11	9	2	33
	Decreased	9	8	6	1	24
	Unchanged	8	7	5	3	23**
	Total	35	34	22	9	100
X-Ray	Improved	8	7	7	3	25
	Unchanged	18	18	9	5	50
	Increased	9	9	5	1	24†
	Total	35	34	21†	9	99†

* Normal before and after therapy.
** Appreciable correction of deformity in 18.
† One patient showed no changes by roentgenogram before or after therapy.

There has been no satisfactory explanation for the effect of roentgenotherapy. Blair advanced the theory that the rays bring about beneficial results by affecting the chemistry of the mast cells, located in the connective tissues around the blood vessels as well as in the synovial tissues. Oppenheimer conjectured that perhaps radiation therapy causes the calcification or ossification of the capsule to disappear, in analogy to the effect upon calcification in bursae and tendons.

CONCLUSIONS

From clinical observations it appears that the roentgen irradiation affects the cellular changes of Marie-Strümpell arthritis, but we have no evidence that it affects the associated ossifying process once it is under way.

In a series of 100 patients with Marie-Strümpell arthritis, treated by roentgenotherapy plus corrective measures, the results, based on relief of pain, range of motion, and roentgenographic changes, indicate that the therapy can be expected to give approximately the same relief from pain during any stage of the disease. Increase in range of motion can be expected in a fair percentage of the mild and moderately advanced cases. Although there is relief from pain, a decrease in range of motion and further ossification may occur. In the mild or moderately advanced cases, the process can be arrested and in some instances cleared by the roentgenotherapy. Of the forty-seven patients in the mild and moderately advanced groups, fifteen showed roentgenographic clearing of the bone changes; twenty-four showed no change or advance in the disease; only seven showed advance with additional ossification. Comparison with the advanced group of thirty-two patients shows that roentgenographic improvement can be expected in the earlier cases more frequently than in the advanced cases, where the changes are no longer reversible.

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DISCUSSION

Dr. Philip D. Wilson, New York, N. Y.: Both of these papers are thought-provoking. The reason for associating them together for discussion obviously is the similarity of the changes about the sacro-iliac joints, as shown by x-ray examination, which may easily lead to errors in diagnosis. The fact that these authors, who are expert in the recognition of the signs and roentgenographic changes of these two diseases, admit making diagnostic errors is proof of this, and is a warning to others to be careful in diagnosis.

The questions I would like to raise are whether osteitis condensans ilii is really a disease and whether these roentgenographic changes are of clinical significance. I think none of us can be sure. The symptoms are remarkably similar to those of patients with low-back strain. In some of the cases I have observed, the symptoms were intermittent, although the changes seen in the bone did not vary. If the symptoms are caused by pathological changes in the bones, it seems strange that the patients should have periods of complete relief from pain. One wonders whether these symptoms are not caused by low-back strain, and if the findings by x-ray are of any real clinical significance. I think we cannot ignore these findings, but we should not be too quick in drawing conclusions.

The theory of Dr. Shipp and Dr. Haggart as to the cause of this condition does not hold water, in my opinion. I doubt that the rotatory motion of the sacrum will make the lower part of it act on the iliac surfaces as a battering ram and produce bone condensation. I can't conceive of its acting in this way without itself participating in the changes.

I would expect to find condensation also on the sacral side, but we don't. I should also expect to see signs of wearing away of the joint cartilages and osteo-arthritic changes. I think that these bone changes are much more likely to be associated with vascular changes in the bone and that they may be due to some type of avascular necrosis. Pregnancy may play a role, as the changes are seen only in women.

Dr. Baker and his associates have presented a first-class paper which adds something to our knowledge. We are always questioning whether or not ankylosing spondylitis is a separate disease from rheumatoid arthritis of the spine, and they present evidence to show that it is. Serological and biochemical studies have

been made in the two groups of cases, and the results were different in the cases of ankylosing spondylitis from those seen in rheumatoid arthritis. Certainly from my own clinical observations of these diseases, I am willing to agree that ankylosing spondylitis is a separate entity.

I think their studies of the results of radiation therapy, which is the main purpose of their paper, are really quite remarkable. They agree with the earlier studies of Freiberg which were to the same effect, and I believe from my own clinical experience that these patients obtain relief of pain. We use this method routinely at the Hospital for Special Surgery and we are satisfied with the results. That these patients also show improvement in range of motion is more doubtful, in my opinion, although Dr. Baker's careful measurements seem to indicate it. I should want more proof before accepting this.

As regards the improvement in the condensation of the ilium following x-ray therapy, and the improvement in appearance following exercise and postural correction of osteitis condensans ilii by Dr. Shipp and Dr. Haggart, I am not prepared to admit that those are the result of treatment. If we follow these cases long enough, we may find that the condition improves spontaneously and not as the result of treatment.

DR. HARRY C. BLAIR, PORTLAND, OREGON: Dr. Shipp and Dr. Haggart have added to our knowledge and have increased our interest in this rather obscure, ill-defined condition,—osteitis condensans ilii. They have developed a logical conclusion to what is no doubt a prime etiological factor,—namely, excessive strain on the supporting sacro-iliac ligaments. The necessity for doing sacro-iliac fusion for a condition that apparently does not involve that joint gives us food for thought, but the answer seems to be that the patient is relieved of pain. However, the majority of patients were treated by conservative methods with relief.

Dr. Shipp states that the postural defects were treated by training in active muscle exercises and by reduction of excessive weight. From this type of treatment, six of 100 patients revealed, from a roentgenographic standpoint, diminution of the sclerosis. The report of this phenomenon is, I believe, unique.

Dr. Shipp's summary includes the caution that this iliac condensation must be differentiated from Marie-Strümpell disease, and that such differentiation is sometimes very difficult in the early stages. Dr. Baker was one of the first orthopaedic surgeons in this country to treat Marie-Strümpell disease with x-ray. He has reported his findings from time to time, and he is to be congratulated on his continued enthusiasm in this respect. Many patients are progressively becoming hopeless invalids because we do not watch them with enough persistence from month to month and from year to year.

The pathological process in Marie-Strümpell disease consists in the absorption of cartilage with a concomitant disturbance of the adjacent bone. When all the cartilage has been absorbed, bone is laid down with resulting ankylosis and ossification of ligaments in articular spaces. The symptoms then disappear and the sedimentation rate decreases. X-ray treatment usually brings about relief in a very short time. Its use causes a metabolic process that can only be explained by the production or the increase of some substance in the body which inhibits the pathological process of this disease immediately.

It is hoped that Dr. Baker will continue his interest in this stubborn, crippling condition, so that he can stimulate us to persevere in our treatment to help stop the progress of this insidious disease.

DR. FRANK L. SHIPP (closing): The tests for sacro-iliac function which we have found most efficacious have been three. First, with the patient lying supine, the anterior-superior spines of the ilia are sprung apart; second, with the patient lying first on one side and then on the other, the sacro-iliac joints are compressed by manual pressure on the uppermost iliac crest; third, with the patient lying supine, the hip is flexed with the knee in full extension. The straight-leg-raising test, of course, is not specific for sacro-iliac disease, but simply complements the other tests.

As to the value of radiation therapy in the treatment of osteitis condensans ilii, we, too, see a large number of patients with Marie-Strümpell arthritis each year. In the male patients, we use x-ray therapy in much the same way as do Dr. Baker and his associates. In female patients with osteitis condensans ilii, x-ray therapy has not been employed, while in those with Marie-Strümpell arthritis, it has been withheld except as a last resort. There are two considerations behind this decision,—first, possible interference with menstrual function and, second, the unknown effect that such therapy may have on progeny.

We wish to emphasize again that neither the clinical history nor the subsequent course of these patients parallels that of the individual with Marie-Strümpell arthritis. In the present follow-up, which now extends over five and one-half years, we have observed a marked difference in the course of these two groups of patients. As pointed out previously, even those patients with osteitis condensans ilii who showed the least response to treatment exhibited no restriction of motion in either the spine or the chest, nor did the apophyseal joints show evidence of arthritic involvement.

As noted by Dr. Wilson, perhaps this condensation about the sacro-iliac joint is comparable to the sclerosis seen in the innominate bone in degenerative arthritis of the hip. The difference may lie in the fact that, while the one articulation is amphiarthrodial, the other is diarthrodial in type. Certainly, in those cases which yielded the biopsy material, there was gross fibrillation of the articular cartilage and the picture as a whole suggested changes consequent upon a vascular disturbance.

(*Continued on page 866*)

A STUDY OF THE GROSS ANATOMY OF THE ARTERIES SUPPLYING THE PROXIMAL PORTION OF THE FEMUR AND THE ACETABULUM

BY WILLIAM W. HOWE, JR., M.D., THOMAS LACEY, II, M.D., AND R. PLATO SCHWARTZ, M.D., ROCHESTER, NEW YORK

From the Division of Orthopaedic Surgery, Department of Surgery, University of Rochester School of Medicine and Dentistry

Knowledge of the arterial anatomy of the hip is essential for an understanding of the pathogenesis of disease affecting the proximal portion of the femur and the acetabulum. The authors have been unable to find, either in the standard anatomy texts or in numerous articles on this subject, a detailed description of the gross relationship and distribution of the arteries to the hip region. To obtain this information, forty human adult hips were dissected by gross anatomical methods. A summary of the findings from these dissections comprises the material for this paper.

ARTERIES SUPPLYING THE PROXIMAL PORTION OF THE FEMUR AND THE ACETABULUM

The arteries supplying this region are: the lateral femoral circumflex, the medial femoral circumflex, the obturator, the superior gluteal, the inferior gluteal, the first perforating artery, and the nutrient artery of the femur. These arteries will be described individually.

Lateral Femoral Circumflex Artery

The lateral femoral circumflex artery originates from the profunda femoris artery near its origin or, less frequently, from the femoral artery (Figs. 1,*e* and 2,*e*). This artery passes laterally over the iliopsoas, where it divides into branches destined to supply muscles, the base of the femoral neck, and the greater trochanter. Muscle branches supply the iliopsoas, the vastus lateralis, and the vastus intermedius; one branch supplies the tensor fasciae latae. It is this vessel which is severed at the medial border of the tensor fasciae latae in a Smith-Petersen approach to the hip joint.

Branches supplying the anterior portion of the femoral neck also originate at the lateral border of the iliopsoas. They pass lateral to the iliopsoas and course deeply to reach the femur at the intertrochanteric line. In this region the arteries supply three areas: the base of the neck extracapsularly along the intertrochanteric line, the capsule, and the intracapsular neck. Numerous small branches supply the base of the neck along the length of the intertrochanteric line. Small branches from these vessels terminate in the ligamentous capsule near its insertion on the femur.

The artery destined to enter the intracapsular neck is consistently of good caliber (Figs. 1,*f* and 2,*f*). It always pierces the less dense section of the anterior portion of the capsule close to bone, between the ascending and transverse bands of the inverted Y ligament of Bigelow. Within the capsule this vessel lies beneath the visceral synovial membrane. Thirty-three dissections were made of this artery. In thirteen the artery entered bone immediately after piercing the capsule. From five of these an additional branch continued proximally to enter the mid-portion of the neck. In fourteen specimens the artery passed upward, without branching, to enter the mid-portion of the neck. In the remaining six dissections the artery entered a foramen close to the articular rim of the femoral head. The caliber of these vessels to the proximal portion of the neck decreased markedly in the subcapital area. An occasional small intracapsular branch from the artery, piercing the Y ligament, ascended subsynovially along the intertrochanteric line beneath the transverse portion of the iliofemoral ligament, terminating on the superior

portion of the neck near the superior capital vessels from the medial femoral circumflex artery.

Two or three trochanteric vessels continue laterally to supply the anterior and lateral surfaces of the greater trochanter. The most superior of these ascends to distribute in the region of the glutaeus minimus insertion, and there it may anastomose with the branches of the medial femoral circumflex artery to the superior portion of the neck (Figs. 1,*j*, 2,*j*, 5,*j*, and 6,*j*). One or two more vessels enter the bone of the greater trochanter anteriorly. The most inferior branch passes over the vastus intermedius, continues laterally under the upper portion of the vastus lateralis, and curves around the lateral surface of the femoral shaft (Figs. 1,*h* and 2,*h*) where it lies just distal to the femoral tubercle to which is attached the vastus lateralis. From there the vessel is distributed to the lateral surface of the trochanter and may anastomose with the superior gluteal artery (Fig. 2). It then continues posteriorly, where its branches are distributed in an area in common with the first perforating artery. This inferior trochanteric branch of the lateral femoral circumflex artery is the heavy bleeder frequently cut during exposure of the femur for internal fixation of a fractured femoral neck.

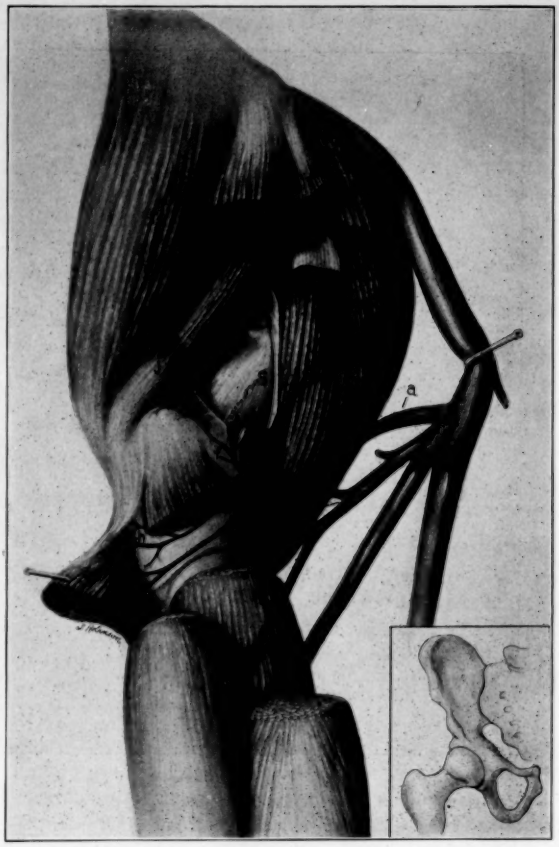

FIG. 1

Anterior view.

a: Medial femoral circumflex artery.
e: Lateral femoral circumflex artery.
f: Anterior cervical branch of lateral femoral circumflex artery.
g: Anterior capital branch of lateral femoral circumflex artery.
h: Trochanteric branch of lateral femoral circumflex artery.
j: Branch of lateral femoral circumflex artery near point of anastomosis with medial femoral circumflex artery.

Medial Femoral Circumflex Artery

The medial femoral circumflex artery arises either from the profunda femoris artery or, less commonly, from the femoral artery. Immediately it dips posteriorly between the iliopsoas and pectineus (Fig. 1,*a*). During its course posteriorly it supplies branches to the adductor muscles, gracilis, and obturator externus. Near the adductor brevis in some of our specimens an obvious anastomosis existed between the muscle branches of the medial femoral circumflex artery and the obturator artery. In no specimens did the medial femoral circumflex artery send a separate vessel into the acetabular fossa, as has been described in the literature.

Viewing the vessel from a posterior approach (Figs. 3,*a* and 4,*a*), it lies in the trochanteric fossa proximal to the lesser trochanter, to which it gives three or four small

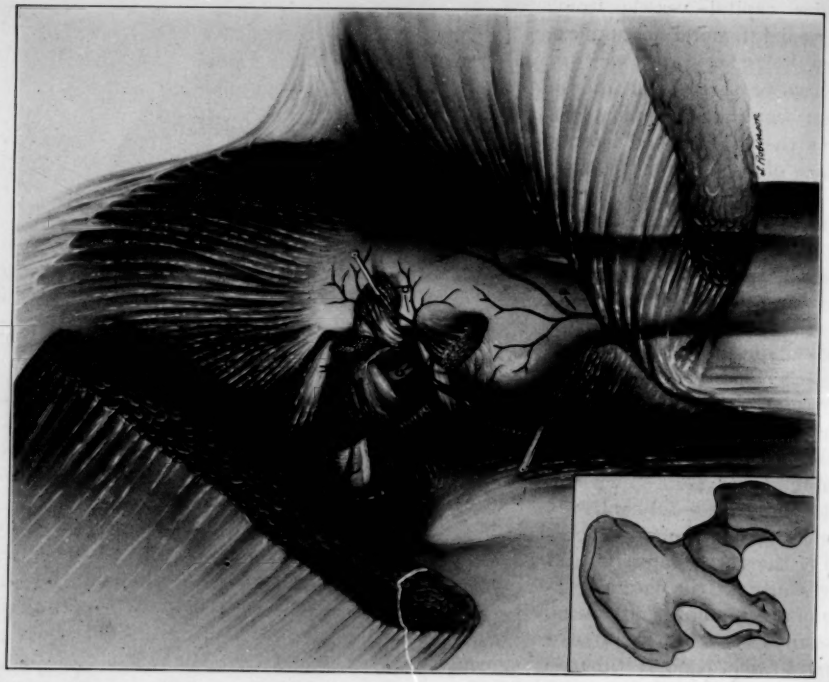

FIG. 3

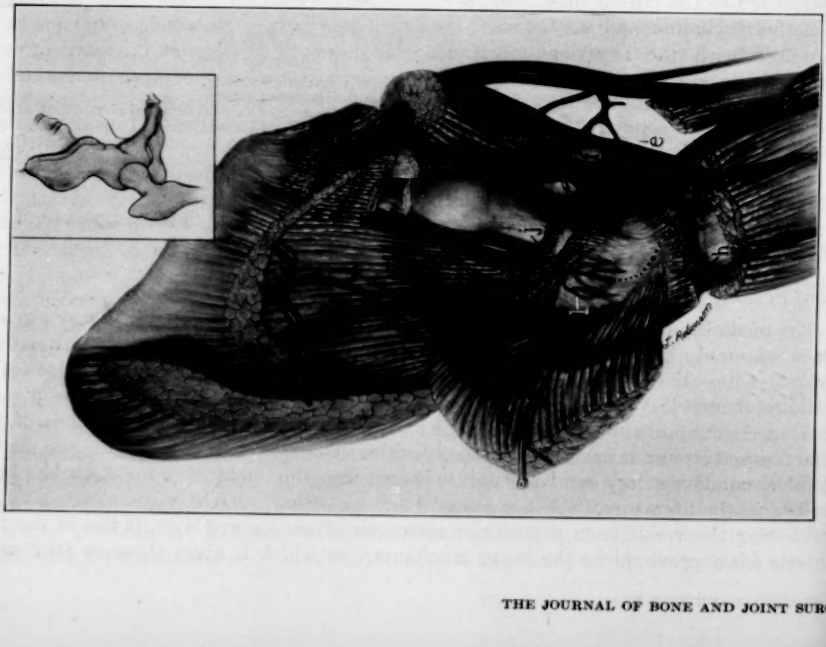

FIG. 2

Fig. 2: Anterolateral view.
e: Lateral femoral circumflex artery.
f: Anterior cervical branch of lateral femoral circumflex artery.
h: Trochanteric branch of lateral femoral circumflex artery.
j: Anastomosing branch to medial femoral circumflex artery.
l: Trochanteric branches of superior gluteal artery.

Fig. 3: Posterior view.
a: Medial femoral circumflex artery.
c: Posterior superior capital branch of medial femoral circumflex artery.
d: Trochanteric branches of medial femoral circumflex artery.
m: Inferior gluteal artery.
p: Trochanteric branches from first perforating artery.
s: Branch of inferior gluteal artery to external obturator foramen.
u: Branch of inferior gluteal artery to internal obturator and gemelli.

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vessels. In this area arises the posterior inferior vessel to the femoral head (Fig. 4,*b*). After passing beneath the obturator externus, this branch penetrates the thin parietal capsule at its insertion to the base of the femoral neck. Protected by a thickened visceral synovial membrane, this vessel courses up the neck to supply the femoral head with two small vessels at the articular rim. Smaller branches from these vessels are distributed to the visceral synovial membrane in this region; occasionally there are one or two branches into cervical bone.

During passage proximally in the fat-filled trochanteric fossa, numerous branches enter foramina in the trochanteric fossa to supply the base of the neck (Fig. 4). At the lower border of the obturator externus, one or two trochanteric branches of good size curve out over the posterolateral surface of the greater trochanter (Figs. 3,*d*, 4,*d*, 5,*d*, and 6,*d*). The main vessel continues superiorly over the obturator externus to reach the superior surface of the neck (Figs. 3,*c*, 4,*c*, 5,*c*, and 6,*c*). Here it lies deeply buried and protected beneath the common tendon of the obturator internus and the gemelli, and the overhanging superior tip of the greater trochanter. In order to see the vessel clearly in this region, it was necessary to remove this portion of the trochanter with the tendinous insertion of the internal obturator (Figs. 5 and 6). As this vessel reaches the short, flat superior neck, two or three large branches enter the neck near the junction with the greater trochanter. In the same area three or four large vessels pierce the lateral capsular insertion and then, passing proximally beneath slightly thickened visceral synovial membrane, enter four to five large foramina at the articular rim of the superior portion of the femoral head (Figs. 5,*c*, 6,*c*, and 7,*c*). These vessels were constantly of large caliber and nearly unvarying in number.

Obturator Artery

After passage through the obturator foramen, the obturator artery lies deeply buried beneath the obturator externus, forming by its branches a vascular ring about the origin of this muscle (Fig. 8,*o*). At the acetabular notch a single branch passes beneath the transverse ligament and enters the fat of the acetabular fossa (Fig. 8,*r*). A relatively small branch from this acetabular artery enters the substance of the ligamentum teres (Fig. 8,*t*). In the acetabular fossa, branches in abundance are distributed to fat, synovial membrane, and acetabular bone. In the authors' dissections the vessel coursing in the substance of the ligamentum teres represented a small portion of the terminal supply of the acetabular branch from the obturator artery. In all of the specimens one or, less frequently, two small arteries were found passing through the ligamentum teres toward the femoral head. These vessels were too small to permit demonstration of their passage into bone at the fovea centralis by gross anatomical methods.

In the posterior section of the obturator foramen a branch from the inferior gluteal artery frequently joins the obturator-vessel ring (Fig. 8,*s*). Several branches from these two arteries enter foramina in the inferior posterior portion of the acetabulum (Fig. 8). In the anteromedial section of the external obturator ring, the medial femoral circumflex

artery less frequently sends a branch from the region of the adductor muscles. This participation of the medial femoral circumflex artery and the inferior gluteal artery in the circulation of the external obturator ring was easily demonstrated grossly in about one third of our specimens; in another third it was suggested as potential, although not demonstrable grossly.

Superior Gluteal Artery

The superior gluteal artery supplies the superior portion of the acetabulum, the upper parietal ligamentous capsule, and a small portion of the greater trochanter. As the superior gluteal artery emerges through the sciatic notch, a branch descends beneath the pyriformis to supply the posterior rim of the acetabulum and the posterior ligamentous capsule. Another branch passes transversely along the ilium beneath the glutaeus minimus, nourishes that muscle, and also sends several arteries through foramina into the superior portion of the acetabulum. Branches from these vessels descend to the superior capsule of the hip joint. These vessels terminate within the proximal parietal capsule and could not be demonstrated to pass distally into the femur. The branch of the superior gluteal artery which supplies the glutaeus medius courses beneath that muscle and sends a terminal branch to the femur (Fig. 2,*l*). Small twigs are distributed around the insertions of the glutaeus medius and glutaeus minimus, as well as to the most cephalad tip of the greater trochanter. Descending branches reach an area over the superior and lateral surfaces of the greater trochanter common to terminal branches of the inferior gluteal, lateral femoral circumflex, and medial femoral circumflex arteries.

Inferior Gluteal Artery

The inferior gluteal artery emerges posteriorly beneath the pyriformis and medial to the sciatic nerve (Fig. 3,*m*). In addition to the numerous and large branches to the glutaeus maximus, there are two main branches to deeper structures of the hip. A transverse branch passes over the sciatic nerve, to which it supplies a vessel. Shortly after passage over the nerve, a branch dips inferiorly to supply the inferior and posterior portions of the acetabular rim and adjacent ligamentous capsule. A continuation laterally (Fig. 3,*u*) passes between the internal obturator and the gemelli group and the pyriformis. Numerous small branches from this artery are distributed about the insertions of these muscles and the glutaeus medius on the superior posterior tip of the trochanter. In this region, passage of vessels into the femur was not demonstrated.

Medial to the sciatic nerve, a branch to deeper structures descends abruptly between the nerve and the posterior portion of the acetabulum. This branch then proceeds anteriorly around the ischium, in the notch between the inferior portion of the acetabulum and the ischial tuberosity, to reach the external obturator fossa (Fig. 8,*s*), where this vessel anastomoses with the obturator artery and supplies the bone of the inferior portion of the acetabulum.

First Perforating Artery

In all of the specimens, a good-sized branch from the first perforating artery supplied the posterior surfaces of the greater and lesser trochanters (Fig. 3,*p*). The main vessel arises from the deep femoral artery and pierces the upper portion of the adductor magnus, to lie beneath the insertion of the glutaeus maximus. In addition to several branches to the glutaeus maximus and adductor magnus, a large branch ascends the femoral shaft beneath the glutaeus maximus insertion. At the inferior border of the quadratus femoris, it divides to send a smaller branch to the posterior inferior surface of the lesser trochanter and another branch to the posterior inferior surface of the greater trochanter. Both of these vessels reach a common vascular area with the medial and lateral femoral circumflex arteries.

FIG. 4

FIG. 5

Fig. 4: Posterior view of proximal portion of upper femur.
a: Medial femoral circumflex artery.
b: Posterior inferior capital branch of medial femoral circumflex artery.
c: Posterior superior capital branch of medial femoral circumflex artery.
d: Trochanteric branches of medial femoral circumflex artery.

Fig. 5: Superior view of femoral head and neck (tip of trochanter has been removed).
c: Posterior superior capital branch of medial femoral circumflex artery.
d: Trochanteric branch of medial femoral circumflex artery.
j: Branch of lateral femoral circumflex artery anastomosing with the medial femoral circumflex artery.

Fig. 6: Superior view of femoral head and neck (tip of trochanter has been removed).
c: Posterior superior capital branch of medial femoral circumflex artery.
d: Trochanteric branch of medial femoral circumflex artery.
j: Branch of lateral femoral circumflex artery anastomosing with the medial femoral circumflex artery.

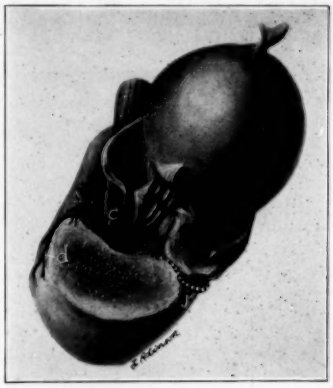

FIG. 6

Nutrient Artery

The nutrient artery was dissected inside the fatty marrow cavity in fourteen specimens. By splitting the proximal half of the femur, the main vessel was easily found (Fig. 7,*n*). At the upper end of the hollow femoral shaft, the artery terminated in numerous small branches. In none of the specimens did the nutrient artery appear to distribute branches proximally beyond the marrow cavity. From this material we believe that the nutrient artery contributes a relatively insignificant blood supply to the femoral trochanters, neck, and head.

DISCUSSION OF THE CIRCULATION TO THE PROXIMAL PORTION OF THE FEMUR

The literature on the arterial supply to the proximal portion of the femur is abundant. Many differing interpretations have been expressed. In correlating our own observations with those of others, each vessel will be considered separately.

Foveal Arteries

The foveal arteries have been studied extensively. In children, Kolodny and Vereby found foveal vessels supplying the ossification center of the femoral head. Nussbaum, Walmsley, and Wolcott, however, at no time found the foveal vessels penetrating into the ossification center. Wolcott, using injection material, could not demonstrate vessels entering the head until the age of ten, when the ossification center enlarges and approaches the fovea centralis. Tucker has recently given the results of his study of this specific question. In 33.3 per cent. of his twenty-four specimens in children up to thirteen years of age, the foveal vessels penetrated to the ossification center. No mention was made of whether or not the arteries penetrating to the ossification center were in the older children. These vessels, one to five in number, had a mean diameter of 0.183 millimeter.

There has been slightly less controversy over the arteries entering the head in the adult by way of the ligamentum teres. Nussbaum and Kolodny found vessels in the round ligament, but minimized their contribution to the nourishment of the femoral head. Chandler and Kreuscher studied microscopic cross sections of 114 ligamenta teretia; 75 per cent. of these contained arteries from 0.2 to 1.5 millimeters in diameter. In the remaining twenty-eight the arteries were small, sclerosed, or not significant. Nordenson studied 129 specimens in which the ligamentum teres was normal. Of these, 70.5 per cent. contained good-sized arteries. In the remaining 29.5 per cent., the arteries were small or did not enter the head. In an unstated number, Wolcott found significant arteries in 80 per cent. of adult round ligaments, but 20

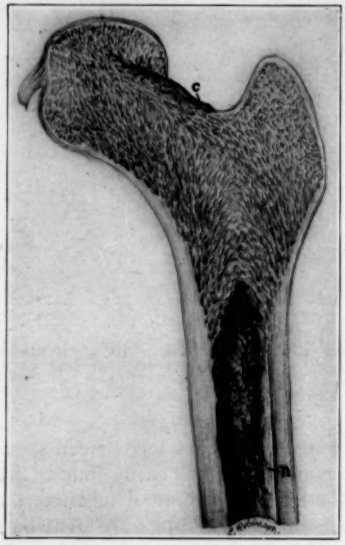

FIG. 7

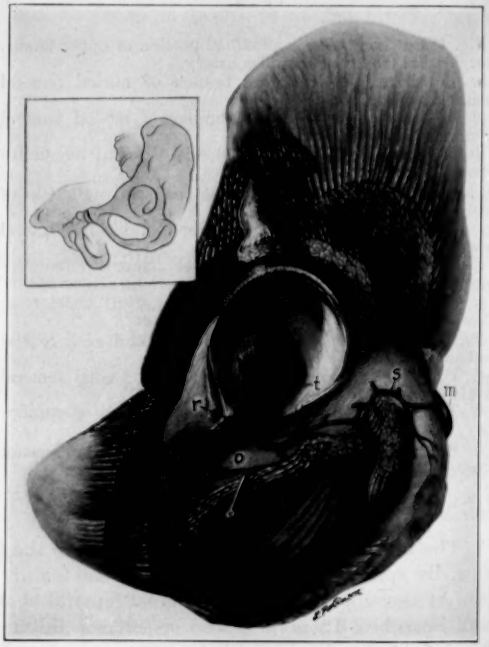

FIG. 8

Fig. 7: Coronal section of proximal portion of femur.
c: Posterior superior capital branch of medial femoral circumflex artery.
n: Nutrient artery.

Fig. 8: View of acetabular fossa.
m: Inferior gluteal artery.
o: Obturator artery.
r: Branch of obturator artery to cotyloid fossa.
s: Anastomosis between inferior gluteal artery and obturator artery.
t: Branch to ligamentum teres.

per cent. of these failed to continue into the femoral head. Tucker found an artery in each of twenty ligaments with penetration into the head in 70 per cent. These vessels had a mean diameter of 0.328 millimeter, an 80 per cent. increase in size over those in children.

Numerous animal experiments have been made in which the ligamentum teres has been severed. Graham and Zemansky and Lippmann produced slight changes in the femoral head in rabbits after section of the ligamentum teres. Stewart, Kistler, and Miltner and Hu were unable to detect evidence of avascular necrosis after section of the ligamentum teres in young or mature rabbits and dogs.

Nordenson provided an interesting observation. In twenty round ligaments from cases of fracture of the femoral neck, he always found arteries considerably larger than those from a normal specimen. Clinically, Phemister emphasized the revascularization of the partially necrotic head by the foveal vessels. Phemister and others have described several pathological specimens which have shown an area of vascularity at the fovea centralis in an otherwise necrotic head.

The authors consistently found a large vessel entering the acetabular fossa, and this contributed a small branch or two to the ligamentum teres. These branches to the ligamentum teres were always considerably smaller than the posterior capital branches of the medial femoral circumflex artery.

In summary, it would seem that in children the foveal vessels assume a small role in supplying the femoral head. When arteries do penetrate to the ossification center, they are probably supplementary. In the adult the foveal arteries are larger and usually nourish the femur. Although these arteries usually remain intact after fracture of the femoral neck, in many cases they seem inadequate, despite dilatation, to assume a major portion of the nourishment of the femoral head. In traumatic dislocations of the hip, however, when the ligamentum teres must frequently be severed, avascular necrosis is a less common sequela than in fractures of the femoral neck. It would appear, therefore, that, although the arteries through the ligamentum teres do supply the femoral head in the majority of cases, this supply is usually supplementary to the vital supply from the other capital arteries.

Posterior Capital Arteries

The medial femoral circumflex artery has long been recognized as the artery supplying the principal capital blood supply. Sir Astley Cooper early emphasized the importance of the capital branches of the medial femoral circumflex artery for the nutrition of the femoral head. Several papers have been published concerning this circulation, especially in the German literature [8, 11–13, 18]. All investigators have found the terminal branches entering the femoral head at the articular rim, just posterior to the superior and inferior poles of the femoral neck. In children these branches course proximally to pass over the epiphyseal plate, and then angulate sharply to reach the ossification center. This proximal entrance into the femoral head is maintained in the adult. Vereby described equal capacity for both the superior and inferior arterial groups. Most investigators have found that the superior posterior branches are usually larger and more numerous. Nussbaum found two to five superior branches supplying the upper two thirds of the femoral head and one or two branches inferiorly, supplying the lower third of the head. Tucker measured these branches and found the superior posterior ones to have a mean diameter of 0.839 millimeter in adults and 0.730 millimeter in children; the posterior inferior ones had a mean diameter of 0.410 millimeter in adults and 0.467 millimeter in children. In our dissections we found an average of three (one to five) large branches entering the head superiorly and one or two inferiorly. The superior vessels were consistently larger than the inferior ones.

Wolcott has shown that these capital branches of the medial femoral circumflex artery are the only arterial supply to the ossification center in the growing femoral head.

Stewart, Kistler, and Miltner and Hu have produced avascular necrosis in animals by obliterating these arteries, but the incidence was higher when both the foveal and capital vessels were obliterated. From the several works just reviewed and from observations in the present series, there is strong evidence that both of these groups, especially the superior posterior group, furnish the major arterial supply to the femoral head.

In studying these arteries, the emphasis in the past has been on their distribution within the femur. The course and relationships of the medial femoral circumflex artery and its branches from the origin of the artery have for some reason been less well reported. Nussbaum, on the basis of a few cases, and Vereby, on the basis of more, described their composite findings of this gross anatomy. In the English literature there has been confusion and, even in the anatomy textbooks of Gray and Piersol, a surprising lack of detail concerning this artery and its relations about the hip. It is hoped that the descriptions and illustrations based on the authors' forty dissections will help in clarifying the anatomical relationships of this artery, and will assist the surgeon in avoiding these vulnerable and vital arteries.

We believe it is unfortunate that these vessels nourishing the femoral head have been labeled the capsular arteries. The name implies that the arteries course in the substance of the parietal capsule, and they are sometimes illustrated in just such a manner. Our dissections show conclusively that the arteries supplying the parietal capsule do not progress into the femur, and, further, that the arteries destined to supply the femoral head do not at any time pass within the substance of the parietal joint capsule. Both the branches of the lateral femoral circumflex artery entering anteriorly and those of the medial femoral circumflex artery entering posteriorly pass through apertures in the capsule, close to its insertion into bone. That these capital arteries are vulnerable in their course along the femoral neck and not in the parietal capsule, should be appreciated by the surgeon.

Because of the misconception which is created, we believe that the descriptive name of capsular arteries is unsatisfactory. Tucker suggested the term "retinacular arteries". We have come to call them the *capital* arteries.

Anterior Capital Arteries

Most investigators have found no arteries entering the femoral head or neck anteriorly. Nussbaum, however, found a single branch of the lateral femoral circumflex artery, which usually supplied the neck anteriorly. Vereby substantiated this and occasionally found an anterior vessel to the head. Tucker could demonstrate vessels on the anterior aspect of the neck in 65 per cent. of children and 25 per cent. of adults. These were small, measuring about 0.184 millimeter in diameter in children as compared to 0.250 millimeter in adults. He did not mention the frequency with which these vessels could be traced into the femoral head. The authors invariably demonstrated a significant artery entering the base of the neck anteriorly. This artery occasionally sent a branch proximally along the neck; in a few cases this branch continued as a very small vessel to the femoral head. In such specimens this small anterior branch to the femoral head, in contrast to the much larger posterior capital vessels, did not appear to play a significant role in the nutrition of the femoral head.

Cervical Arteries

Almost all writers [12, 17, 18, 21] have agreed that the neck vessels in the child do not penetrate the epiphyseal plate to reach the femoral head. Kolodny and Tucker described the nutrient artery as coursing proximally through the neck to the head in the adult, but Lexer found no significant contribution to the cervical or capital supply by the nutrient artery. The authors found a generous arterial supply to the femoral neck from the medial femoral circumflex and lateral femoral circumflex arteries, but did not in any case

trace the nutrient artery past the marrow cavity. These cervical vessels have been demonstrated by several investigators, with the aid of injection techniques, to anastomose freely in the adult with the capital arteries and, in some cases, with the foveal arteries as well. In mature animals both Stewart and Kistler were unable to produce avascular necrosis by obliteration of the foveal and capital vessels, whereas in young animals avascular necrosis of the head followed such a procedure. This indicates the significant anastomosis which occurs between the cervical and capital vessels after closure of the epiphyseal plate. In the adult, these cervical branches add an important source of nourishment to the femoral head.

SUMMARY

The blood supply to the acetabulum, to the trochanters, and to the neck of the femur is abundant and is derived from several arteries.

Nourishment of the femoral head in the adult is supplied by the foveal and cervical arteries, but to a greater degree by capital branches of the medial femoral circumflex artery which course along the neck to enter the femoral head at the articular rim. The vulnerability of these vital arteries explains the high incidence of avascular necrosis of the femoral head.

NOTE: Illustrations of the dissections were drawn by Mr. Leslie F. Robinson of the Medical Art Department under the direction of Mr. Natt Jacobs. The authors are indebted to Karl E. Mason, Ph.D., and Charles E. Tobin, Ph.D., of the Anatomy Department for providing the anatomical material, and to Mrs. Otto Thaler for translating the German articles.

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DISCUSSION

(*Continued from page 855*)

We have yet to find roentgenographic evidence of pre-existing osteitis condensans ilii in routine lumbosacral films of elderly patients, whereas we often see what we believe are the healed or inactive changes of Marie-Strümpell arthritis. Whether this sclerosis of the ilium disappears because of the increasing rigidity of the spine in senescence remains to be seen.

In regard to Dr. Blair's remark about sacro-iliac fusion, a few years ago many patients with radicular pain from intervertebral-disc protrusion were relieved of symptoms by sacro-iliac fusion and, what was probably more important, by the bed rest that went with it.

In closing, we ask you only to weigh the evidence which you have heard and, if you accept our concepts as tenable, to include osteitis condensans ilii in your differential diagnosis in the female patient with low-back pain.

Dr. Lenox D. Baker (closing): Dr. Wilson and Dr. Blair have pointed out several interesting points. Dr. Blair's work on the probable effect of radiation is mentioned in the paper and he is to be commended. His theory should be investigated further. Dr. Wilson, from one of his remarks in regard to the cases of osteitis condensans ilii, apparently is of the opinion that they were included in our series in error. They were not included in the series in error; they were mentioned to point out the identical clinical course of this so-called disease entity with that of Marie-Strümpell arthritis. We are of the opinion that they are of the same etiology. Both groups of patients give a history of early morning back pain relieved by exercise, and the response to x-ray therapy is the same.

It may be well to make a few remarks in regard to the purpose of this follow-up study. It has been known that roentgenotherapy will relieve satisfactorily the pain of Marie-Strümpell arthritis, but the effect of the therapy on the course of the disease has not been established. The study was made in the hope that the patients could be given a more definite prognosis than has been possible in the past. The disease is common. The patients know the possible disastrous results and they are apprehensive. Depending upon the stage of the disease at which the therapy is given, the early response, the changes in the roentgenograms, the frequency of recurrence, and other factors, it was thought that the study might give some idea of the patient's chance for recovery. Some of these questions have been answered in part.

When giving roentgenotherapy to females, the possibility of sterilization is always discussed thoroughly with the patient. Papers are signed as to responsibilities, et cetera. Of approximately thirty female patients who have been treated for osteitis condensans ilii or Marie-Strümpell arthritis, to our knowledge only three have shown any menstrual disturbance. If my memory serves me correctly, one went for three months without menstruating, one menstruated for two cycles and then failed for about six months, and one noted some irregularity for four cycles. The number of r units given is reduced in the female as compared to the male. No female has been given over 900 units, usually in series of 300 r with long intervals between doses.

VASCULAR FORAMINA AND ARTERIAL SUPPLY OF THE DISTAL END OF THE FEMUR

BY WILLIAM M. ROGERS, PH.D., AND HERMAN GLADSTONE, M.D., NEW YORK, N. Y.

From the Department of Anatomy, College of Physicians and Surgeons, Columbia University, New York City

This is an anatomical study of the arterial supply of the lower end of the femur and of the foramina through which the arteries and veins pass. The chief anatomical interest in the lower end of the femur has been its structural features in relation to the function of the knee joint and to its articular surfaces. Considerable attention has been paid to the attachments of ligaments and tendons. Other aspects, especially the vascular supply, have been relatively neglected. Clinical reports of the vascular supply of the femur deal largely with the upper end of this bone, because of the frequency of ischaemic necrosis of the femoral head following fracture at the proximal end of the shaft.

The usual concept of nutrient arteries is that one or two vessels enter the shaft of a long bone and obliquely perforate the cortex. Large numbers of unnamed nutrient arteries traverse the ends of long bones and are obviously important for growth and maintenance. The foramina through which these vessels pass are both numerous and constant, and are more conspicuous than the one or two nutrient foramina in the shaft. The distal end of the femur presents an excellent example of these scattered foramina. The authors reviewed English, German, and French textbooks and atlases and found no satisfactory description of the detailed vascular channels of the distal end of the femur. Toldt has three drawings showing supracondylar foramina. These are not labeled, but two much smaller openings in the shaft are labeled nutrient foramina. More exact information about the vascular foramina is essential for an understanding of the arterial supply of the bone.

This study is divided into two parts; one deals with the vascular foramina, the other with the arteries which pass through them.

THE VASCULAR FORAMINA

The authors studied the vascular foramina of human femora in 200 adults, sixteen newborn infants, and four juveniles. The femora of ten monkeys were also investigated. In all, the distribution of the foramina followed a constant pattern.

The vascular foramina in the distal end of the femur may be divided into three anatomical groups, depending upon their location: supracondylar, condylar, and intercondylar. The supracondylar foramina are in the distal end of the shaft or metaphysis; the condylar and intercondylar foramina are epiphyseal, if one considers them from the developmental point of view.

Each of these groups forms a perforated area on the bone, which we have called "area cribrosa vasorum femoris". They may be subdivided as follows:

1. Supracondylar:	Anterior
	Posterior
2. Condylar:	Medial
	Lateral
3. Intercondylar	Central or foveal
	Peripheral

Supracondylar Foramina

The anterior group of foramina are just above that portion of the condyle upon which the patella rides,—the patellar surface. Usually there are ten to fifteen large foramina

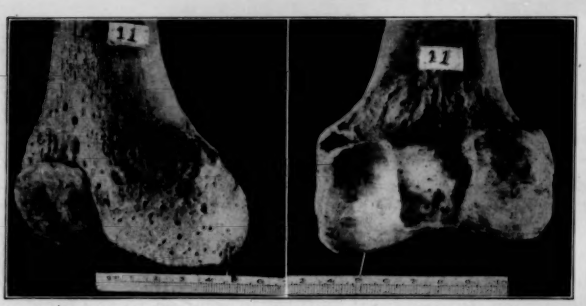

FIG. 1-A FIG. 1-B

Fig. 1-A: Photograph of distal end of a dried femur. Anterior supracondylar and medial condylar groups of nutrient foramina are shown.

Fig. 1-B: Posterior aspect of same femur, showing posterior supracondylar and intercondylar groups.

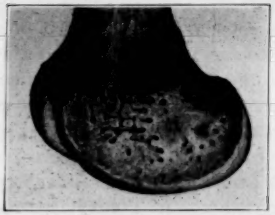

FIG. 2

Fig. 2: Drawing of another specimen, showing a network of furrows on the medial condyle connecting adjacent vascular foramina. Branches of arteries and veins run in these furrows.

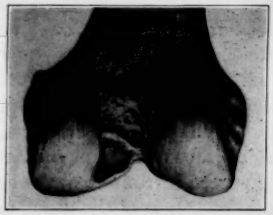

FIG. 3

Fig. 3: Drawing of posterior aspect of distal end of femur shows the intercondylar vascular area situated between the two upper attachments of the cruciate ligaments. A deep fovea containing several vascular foramina is present.

Fig. 4: Photograph of dorsal aspect of the femur of a seven-year-old child having a shallow fovea and five vascular foramina.

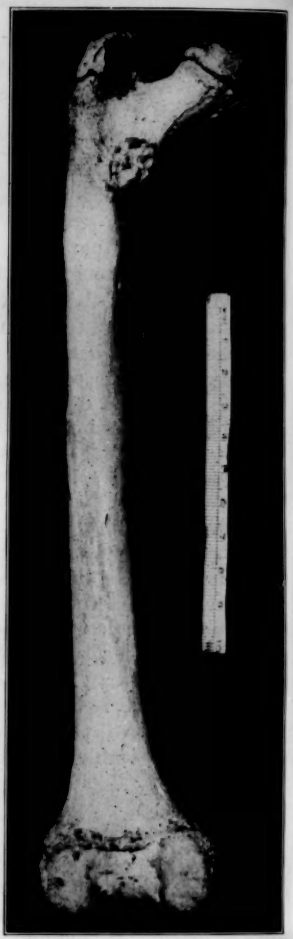

FIG. 4

and greater numbers of small foramina (about twenty) (Fig. 1-A). This portion of the bone could be designated as "area cribrosa vasorum supracondyloidae femoris anterior".

The posterior group of foramina are on the flat dorsal surface of the bone, just above the condyles and the intercondylar line. This area is often referred to as the planum popliteum. About the same numbers of large and small foramina are present as on the anterior surface (Figs. 1-B and 3). This perforated surface may be referred to as "area cribrosa vasorum supracondyloidae femoris posterior". A few small scattered foramina are found occasionally in the medial and lateral supracondylar regions (Figs. 1-A and 2).

Condylar Foramina

About thirty-five foramina are evenly distributed over the entire medial and lateral surfaces of the condyles, except at the areas of attachment of the popliteus and of the medial and lateral heads of the gastrocnemius (Figs. 1-A and 2). Approximately the same number of foramina are found on the medial and lateral condyles of the same bone. In many cases a network of furrows in the cortex connect adjacent foramina (Fig. 2). Arteries and veins lie in these grooves and their branches pass through the foramina. These per-

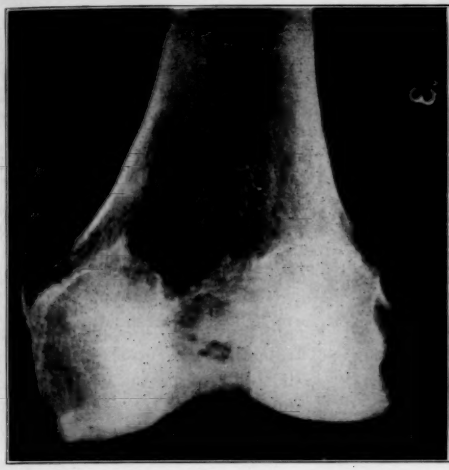

FIG. 5

FIG. 6

Fig. 5: Roentgenogram showing a deep fovea with four large vascular foramina. Supracondylar foramina are also visualized.

Fig. 6: Roentgenogram of specimen having a very deep fovea with foramina and a rarified supracondylar area containing foramina.

Fig. 7: Clinical roentgenogram of knee in an eight-year-old child. A deep fovea, containing several foramina, is seen. (This illustration is presented through the courtesy of John Caffey, M.D.)

FIG. 7

forated areas might be designated as "area cribrosa vasorum condyloidae femoris medialis and lateralis".

Intercondylar Foramina

It seems appropriate to review a conventional description of the intercondylar region[4]: "The floor of the intercondylar fossa is rough, and presents two impressions where the crucial ligaments are attached: that of the anterior ligament occupies the hindmost part of the inner surface of the external condyle, while that of the posterior ligament is at the inner and fore part of the fossa, above the curved portion of the interior tibial articular surface."

No mention is made of a more obvious depression or of the foramina between the two cruciate attachments. There are about fifteen to twenty-five foramina in this area (Figs. 1-B and 3). Several large foramina are at least equal in size to the nutrient foramina of the shaft of the femur. Most of the others are medium-sized openings.

The arrangement of these foramina deserves special attention. In 22 per cent. of the 200 specimens studied, the foramina were evenly distributed over the area bounded in front by the articular surface, on each side by the attachment of the cruciate ligaments, and above by the intercondylar line. The authors have designated this region as the intercondylar perforated area, "area cribrosa vasorum intercondyloidae femoris" (Figs. 1-B and 3).

In the remaining 78 per cent. of the femora, a distinct fovea of from 3 to 8 millimeters was located centrally in the anterior inferior portion of the intercondylar fossa between the attachments of the cruciate ligaments. Within this fovea were five to fifteen large foramina. Of 156 specimens having a definite fovea, 122 (78 per cent.) ranged in depth from 1 to 3 millimeters and were classified as shallow to medium. The remaining 34 (22 per cent.) had a deep fovea, from 3 to 5 millimeters (Fig. 3). This "fovea cribrosa vasorum intercondyloidae femoris" which we are describing represents the "area of rarefaction" observed by Caffey in roentgenograms of living children. The authors' specimens of neonatal femora show vascular canals in their cartilages, but no foveae. In a femur of a child of seven years, a shallow fovea is present (Fig. 4).

Figures 5 and 6 are roentgenograms of two adult femora, in each of which was a rather deep fovea. The films show foramina within the fovea and above the condyles. The entire supracondylar area appears to be less dense. Some of this decreased density is accounted for by the vascular foramina; the remainder is explained by the normal thinning of the cortex and the arrangement of the trabeculae peculiar to this area. Here the opaque trabeculae are more widely separated and are fewer in number, with larger intertrabecular spaces which are radiolucent.

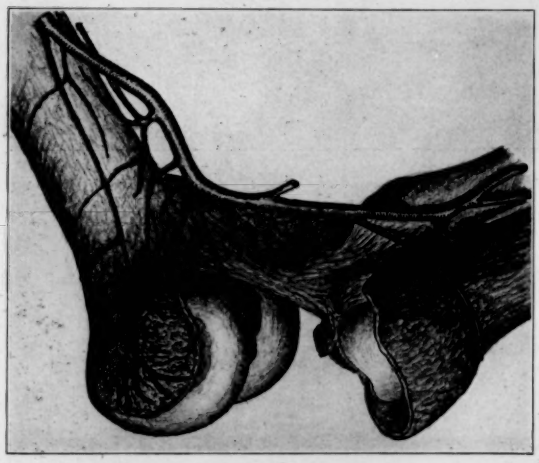

FIG. 8

Fig. 8: Dissection of popliteal artery and its branches to the distal end of the femur.

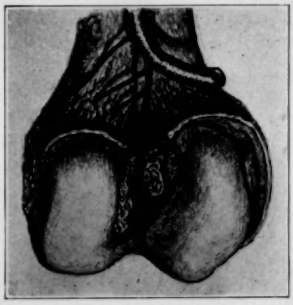

FIG. 9

Fig. 9: Dissection of middle genicular artery, supracondylar and intercondylar branches.

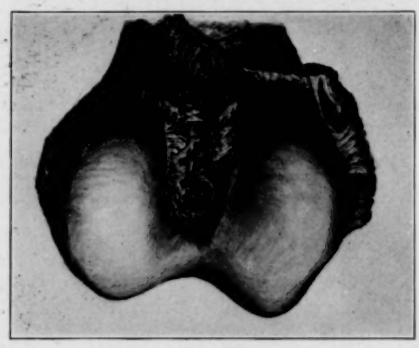

FIG. 10

Branches of middle genicular artery entering intercondylar and supracondylar foramina.

Figure 7 shows the area cribrosa vasorum in a roentgenogram of a living child, eight years of age. One sees four distinct foramina in a sharply outlined fovea, 6 millimeters in diameter. This fovea is centered in the intercondyloid fossa. Frequently foramina can be demonstrated in the absence of a fovea. Caffey has stated that this area of lesser density may be confused roentgenographically with destructive lesions of inflammatory, traumatic, or neoplastic origin.

Femora which have a medium or deep fovea present an area of lesser density in the roentgenogram. This is due to a local depression and thinning in the cortex and steepness of its more or less cylindrical wall. Within this area, the foramina which have their long

axes in an anteroposterior plane cast sharply defined images roentgenographically, while those opening obliquely into the side walls of the fovea are not seen clearly.

THE ARTERIAL SUPPLY

Dissections of the arterial supply of twenty lower extremities after arterial injections of starch and red lead permitted the authors to follow branches of vessels into most of the foramina in the distal end of the femur (Figs. 8, 9, and 10). Figure 8 shows that most of the nutrient rami to the medial condyle and the anterior supracondylar region are from the deep branch of the highest genicular artery and the medial genicular artery. An anastomosis is present between these two arteries. Nutrient arteries to the lateral condyle are chiefly from the lateral superior genicular artery. Rami to the anterior supracondylar area are from both the preceding groups. Arteries to the posterior supracondylar foramina are derived from all of the genicular arteries mentioned. Those to the intercondylar foramina are chiefly branches from the middle genicular artery (Fig. 9). The main continuation of this artery, which is often paired, passes through the superior portion of the popliteal tendon, between the upper attachments of the anterior and posterior cruciate ligaments, and gives off branches to what we have termed the "intercondylar perforated area". As a rule, a majority of the large branches are concentrated in the region of the fovea (Figs. 9 and 10).

FIG. 11

Roentgenogram of distal end of thigh. Mercury had been injected into the femoral artery.

The development of a fovea containing vascular foramina probably depends upon the concentration of the arterial branches. The course of nutrient arteries within the bone was demonstrated by injections of radio-opaque fluids at necropsy. Several types of radio-opaque materials were used. The best results were obtained with a fine emulsion of mercury in turpentine, injected under about twenty-five pounds of pressure into the proximal third of the femoral artery. The injection mass flows into very small vessels and casts sharply defined shadows, visible in roentgenograms (Figs. 11, 12-A, 12-B, 14-A, and 14-B). The anterior and posterior supracondylar rami supply the distal end of the diaphysis. Figure 11 represents a roentgenogram of the lower thigh of a male, twenty-seven years of age, after injection of the femoral artery with the opaque mixture. The general distribution of branches of the popliteal artery to the patella, knee joint, distal end of femur, and related soft tissues is seen.

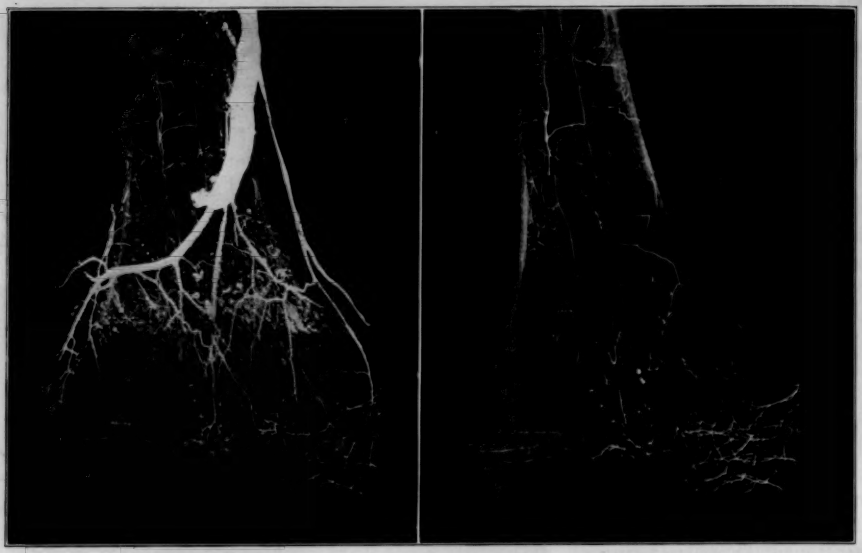

FIG. 12-A FIG. 12-B

Fig. 12-A: Roentgenogram of injected popliteal artery and its branches to the distal end of the femur. Skin, fascia, and muscles have been removed.

Fig. 12-B: Roentgenogram of injected distal end of same femur after removal of the periosteum.

Figure 12-A shows the origin of the genicular arteries from the popliteal artery, and the course and distribution of these arteries to the distal end of the femur.

Figure 12-B depicts the same femur after removal of the periosteum. The injected arteries are all within the bone. Condylar arteries are seen perforating the cortex and ramifying within the spongiosa. Terminal branches of the middle genicular arteries pass through the intercondylar foramina and are distributed to the central portion of the epiphysis. Rami arising from the superior, medial, lateral, and middle genicular arteries pass through the anterior and posterior supracondylar nutrient foramina. These are distributed to the distal end of the diaphysis.

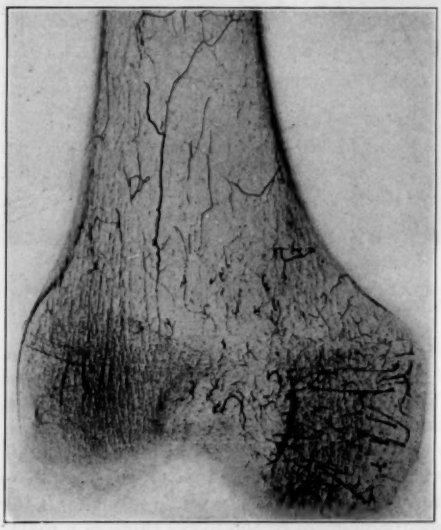

FIG. 13

Roentgenogram of arteries in the distal end of the femur, injected with mercury and turpentine. (Reproduced from Lexer.)

Figure 14-A presents a lateral roentgenogram after both condyles have been removed. It shows the intercondylar arteries passing through the intercondylar foramina and entering the spongiosa. Figure 14-B illustrates the ramifications of the nutrient arteries in the medial condyle.

The medial and lateral condylar nutrient arteries and the intercondylar arteries radiate toward the epiphyseal ossification center in the newborn at full term. In

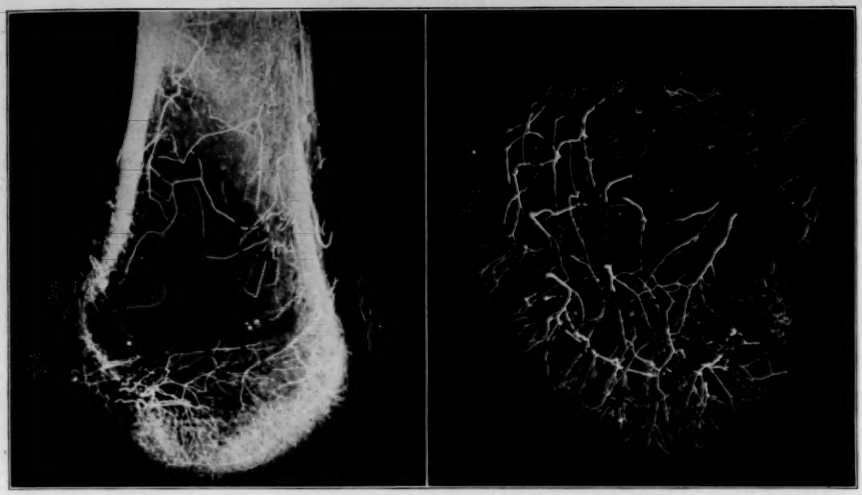

FIG. 14-A FIG. 14-B

Fig. 14-A: Lateral roentgenogram of injected specimen after removal of both condyles. Intercondylar arteries are shown perforating cortex and ramifying in spongiosa.
Fig. 14-B: Roentgenogram of medial condyle of specimen seen in Fig. 14-A, showing distribution of arteries.

premature infants these arteries converge toward the same area before the center has appeared.

Lexer and his associates, in 1904, published a monograph in which they described the arterial supply to all of the long bones and smaller bones. This has been the authoritative work on this subject for many years. The authors have demonstrated a more detailed vascular pattern in the lower end of the femur than that shown in Lexer's plates. A comparison of his plate (Fig. 13) with our Figure 12-B illustrates this.

Langer, in 1875, published a classical description of the blood supply to the distal end of the femur, with excellent plates of dissections of the arteries and veins in that area. Branches of these vessels are shown, forming a network around the distal end. Some of these are indicated as entering the intercondylar incisura. There are no illustrations of the foramina or foveae, although Langer mentioned openings in the sides of both femoral condyles which transmit numerous large arteries and veins. Langer further discussed a third area in the distal femoral epiphysis ("incisura intercondyloidea"), between the two upper attachments of the cruciate ligaments, which contained openings in the bone for branches of the middle genicular artery and vein. He recognized these openings as leading into canals in the spongiosa, which he termed "canaliculi nutritii accessorii".

CLINICAL CONSIDERATIONS

These investigations have demonstrated an abundant arterial supply to the distal end of the femur.

The clinical importance of blood supply in the distal end of the femur, as in the proximal end, relates primarily to fractures and other traumatic injuries. To our knowledge, there has been no reported evidence of ischaemic necrosis following fractures in the distal end. This agrees with our own findings, since it seems unlikely that any fracture would be accompanied by damage to the arterial supply sufficient to cause necrosis, in view of the abundant arterial bed and its collateral circulation.

Tucker stated that there has been objection to the flanged nail in the treatment of fractures of the proximal end of the femur because, if the nail passes through the center

of the head in the region of the artery in the ligamentum teres, it interferes with the blood supply to the head of the femur. Recently the use of metallic angle plates and blade-plates has become popular in the fixation of fractures of the distal end of the femur. The authors' anatomical studies indicate that such plates would probably not interfere with the blood supply.

There has been considerable interest in use of the intramedullary nail for fractures of the femoral shaft during the past few years. The blood supply of the distal end of the femur appears to be adequate for such a procedure.

SUMMARY

1. A number of vascular foramina in the distal end of the femur have been classified according to their anatomical location as supracondylar, condylar, and intercondylar groups. Each group forms a perforated area on the bone.

2. In the intercondylar incisura, between the two upper attachments of the cruciate ligaments, is the intercondylar perforated area. The authors have named this the "area cribrosa vasorum intercondyloidae femoris". Centrally located are a group of foramina usually situated in a cylindrical depression, 3 to 8 millimeters in diameter. In roentgenograms of the dried femora, one sees this fovea as an area of decreased density.

3. The vascular supply to the distal end of the femur has been described on the basis of anatomical dissections. Osteal branches of the genicular arteries and veins can be demonstrated entering all of these foramina.

4. Distribution of these vessels within the bone was studied after injection of an opaque mixture of mercury and turpentine. Roentgenograms showed the distribution pattern of numerous small arteries within the bone.

5. Clinically this generous vascular supply explains the lack of ischaemic necrosis after fractures of the lower end of the femur.

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TENOTOMY IN THE TREATMENT OF SPASTIC PARAPLEGIA

With Special Reference to Tenotomy of the Iliopsoas *

BY LEONARD T. PETERSON, M.D., WASHINGTON, D. C.

Severe spasticity is a distressing complication in paraplegia due to spinal-cord injury or disease, and prevents satisfactory rehabilitation. In this paper, the method of multiple tenotomies is discussed as an effective means of eliminating flexor spasm. The technique described is predicated on tenotomy of the iliopsoas and, in the ten cases reported, multiple tenotomies were carried out in the treatment of spastic paraplegia of varying degree, resulting either from trauma or from disease of the spinal cord. This discussion is not concerned with the treatment of cerebral palsy.

REFLEX SPASM

A comprehensive study of reflex spasm was made by Head and Riddoch, in 1917. Spasticity may appear following injury to the spinal cord, such as severe compression fractures, fracture-dislocations, or war wounds. It may also develop following disease of the spinal cord, such as multiple sclerosis or transverse myelitis.

Spasm is not a factor in every injury or disease of the spinal cord. Its incidence in traumatic cases, however, is relatively high. In one series of 370 cases of paraplegia reported from four Army Neurosurgical Centers, spasticity was present in 154 or 41.6 per cent. Freeman and Heimburger [9] reported spasticity in 230 of a group of 700 paraplegics; in seventy of the cases, spasm was so severe as to require surgical treatment. Gingras, in a study of ninety cases, found 41 per cent. to have spasticity, although the symptoms were mild in 21 per cent. Munro, in a study of 402 spinal-cord injuries occurring in both war casualties and civilians, recorded ninety-one transections of the cord with accompanying spasticity in from 50 to 55 per cent., of which approximately 41 per cent. had severe spasm. In a group of 148 partial injuries of the spinal cord, Munro noted spasm in 11 per cent.; 9 per cent. had spasticity of severe degree.

The cause of reflex activity is still unknown. It has been ascribed by several investigators to the so-called "release" of the isolated segment of the cord from the inhibitory influences of the brain. Scarff and Pool advanced the theory that the source of "mass reflex" lies in the distal stump of the severed cord, and that a "trigger zone" for stimulating reflex spasm exists in the posterior columns.

Spasticity appears within two to ten weeks after injury, when spinal shock, during which the paralysis is flaccid, has worn off. In many cases the reflex activity develops to a heightened state. Spasticity due to spinal-cord disease presents a picture similar to that observed after trauma.

Involuntary spasm may be of the extensor or flexor type, but the flexor type combined with adductor spasm is more commonly encountered. The spasticity may vary in degree. If mild, spasm may not prevent the patient from becoming ambulant; if severe, the patient is seriously disabled.

There is no known correlation between the occurrence, type, or degree of reflex spasm and the level, severity, or nature of the spinal-cord lesion [5, 7, 17, 18, 26, 27, 28]. Spasticity is likely to be increased in the presence of sepsis, anaemia, distention of the bladder or bowel, nephrolithiasis, or decubiti. Infectious diseases, on the contrary, do not appear to aggravate spasticity and, in fact, reflex spasm may improve during an acute illness [14, 21, 27].

The patient with marked flexor-adductor hyperactivity of the lower extremities

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 15, 1950.

presents a pitiful picture. The spasm manifests itself principally in the adductor muscles of the hips and in the flexor muscles of the hips, knees, and ankles. The legs suddenly jerk upward to the chest or "scissor" across each other. So powerful may be the adductor contraction that it is impossible for an examiner to force his hand between the knees; pressure sores invariably develop as the result of the knees rubbing against each other. Flexor spasm at the knees is always present and spastic equinus deformity often develops. A minor stimulus, such as moving the bedclothes or touching the skin, is usually sufficient to evoke the spasms.

The healing of decubiti is retarded. If there is associated spasm of the abdominal muscles with sudden evacuation of the bladder, the urinary problem is further complicated. The spasms are painful, and there is associated pain in the lumbar region. The patient cannot find a comfortable position in bed; he cannot lie on his face; and sleep is disturbed. As a rule, the overactivity of the flexor and adductor muscles eliminates any hope of the patient's becoming ambulatory. In the exceptional patient who can relax sufficiently to stand, psoas spasm may pull him suddenly forward into flexion. In time, secondary contractures develop because of shortening of the flexor muscles and joint capsules.

TREATMENT OF FLEXOR-ADDUCTOR SPASTICITY

Review of Methods

Among the conservative measures adopted have been physical therapy and the administration of curare or prostigimine. Relief of muscle spasm following the use of either curare [6, 19, 22, 23] or prostigimine [1, 21, 23] has been only partial or temporary. Several observers have reported that massage, manipulation, and stretching of the extremities proved to be sources of irritation and actually initiated spasm [10, 28]. Warm baths, passive movements, standing exercises, and ambulation with braces, faradic, and sinusoidal treatment have all been used to reduce the threshold of reflex activity. Although such measures have a relaxing effect, they produce no permanent relief [14–16, 23, 24]. In short, physical therapy has only limited value, and it tends in most cases to become an objective in itself, rather than a means of overcoming spasticity.

Surgical procedures have been used to break the reflex arc, either centrally at the spinal cord or at the periphery. Included in the first group are subarachnoid injections of alcohol, posterior-column tractotomy, and anterior rhizotomy. These measures should be considered only in cases of complete paraplegia, and are not suitable for patients with any voluntary control of the lower extremities. Injections of alcohol have, for the most part, proved of only temporary benefit [16, 20, 34].

Resection of the sensory spinal nerve roots to interrupt afferent impulses, a procedure recommended by Foerster for spastic paraplegia of cerebral origin, has had limited application in spasticity due to spinal-cord involvement [9, 10, 11, 21]. Complete relief has not been obtained by this procedure, and it is not generally accepted. Other surgical measures that have been tried without success in the effort to relieve spasticity are: sympathetic ganglionectomy, continuous spinal and continuous caudal anaesthesia, and excision of the spinal-cord scar [10, 23].

The most widely used surgical procedure in the treatment of "mass reflex" spasm has been anterior rhizotomy, first performed by Munro [28]; through his successful use of this procedure, new interest in handling paraplegics was stimulated. Anterior rhizotomy consists of laminectomy from the tenth thoracic to the first lumbar vertebrae, and division of the anterior nerve roots bilaterally from the tenth thoracic through the first sacral segment. By means of this operation, spastic paraplegia is converted into flaccid paraplegia, and an attempt is made to preserve the innervation of the bladder and bowel.

Munro personally has performed over twenty-five rhizotomies. Freeman and Heimburger have reported twenty-eight rhizotomies for paraplegia in flexion with transverse lesions of the spinal cord; relief from spasm was obtained in all except two cases. Among

other surgeons who have reported successful use of the procedure are: Elkins and Wegner; Botterell, Jousse, Aberhart, and Cluff; Martin and Davis; and Krueger.

Caution is generally advised in the use of rhizotomy. Since the procedure results in complete flaccidity of the extremities, rhizotomy is not justified until either surgical exploration of the spinal cord or the lapse of sufficient time has demonstrated that paralysis is complete and permanent. Many paraplegic patients have some return of voluntary control, and should not be treated by surgery as extensive in scope as rhizotomy. The laminectomy necessary for visualization of the spinal cord may further weaken the back and add to the disability if the patient becomes ambulatory. Further interference with bladder function may follow rhizotomy [4, 25, 34]. Finally, contractures are not relieved and further corrective surgery is required [7, 27, 29, 31]. Of the surgical procedures mentioned, rhizotomy alone has proved efficacious, and it must continue to hold a definite place in the treatment of paraplegic cases with extensor type of spasm and severe spasticity of the trunk muscles.

Among the more common procedures attacking the problem of spasticity peripherally has been neurotomy. Stoffel advanced the idea of severing nerve branches to the overactive muscles. Section of the obturator nerve has come to be generally accepted for the relief of spasm of the common adductor type. The neurotomy may be performed through the intrapelvic or extrapelvic approach, the latter being usually preferred. Section of peripheral nerves, other than the obturator and the fibers of the tibial nerve to the calf muscles, has had little application in the attempt to relieve spastic paraplegia.

Treatment by Tenotomy

Tenotomy is an old-established form of treatment for the relief of contractures, but little use has been made of this procedure in treating spastic paraplegia following trauma or disease of the spinal cord. In recent years, when particular attention has been given to the treatment of spastic paraplegia, the literature on tendon operations has been meager, and mention has been made principally of section of the hamstrings or lengthening of the Achilles tendon. At a Conference on Paraplegia in 1945, at which seven Army Neurosurgical Centers were represented, the subject of tenotomy was dismissed with a single unfavorable comment [32].

The technique of tenotomy to be described was first carried out in July 1947. In the following year, Botterell and Jousse reported five cases of flexor-adductor spasm, in which excellent results had been obtained by combined neurotomies and multiple tenotomies, including section of the iliopsoas. Bors [2] recently reported four cases of bilateral iliopsoas myotomy, performed according to a modified Soutter technique. Good results were obtained in three of the four cases.

Certain fundamental principles are observed in the application of tenotomy to paraplegia with flexor spasm:

1. The procedure is modified in accordance with the degree of paralysis. When paralysis is complete and permanent, spastic muscles are severed without reservation. When voluntary power persists and maximum function must be preserved, the procedure is selective in application. Tenotomy may be limited to one component of a composite muscle, as in partial section of the iliopsoas; tenotomy may be limited in scope and, if necessary, further section of synergistic muscles may be carried out; and, finally, some tendons may be lengthened instead of severed.

2. Postural balance must be maintained in cases with voluntary power. To meet this objective, care is taken to preserve the muscles which control the erect posture. Therefore, the glutaeus maximus, quadriceps, and gastrocnemius-soleus (except in the case of equinus deformity) are not disturbed. The rectus femoris may be sectioned in an occasional case in correcting hip flexion, but, even when sectioned, its action as a knee extensor is perserved. When the glutaeus maximus and quadriceps have been overstretched by the spastic flexors,

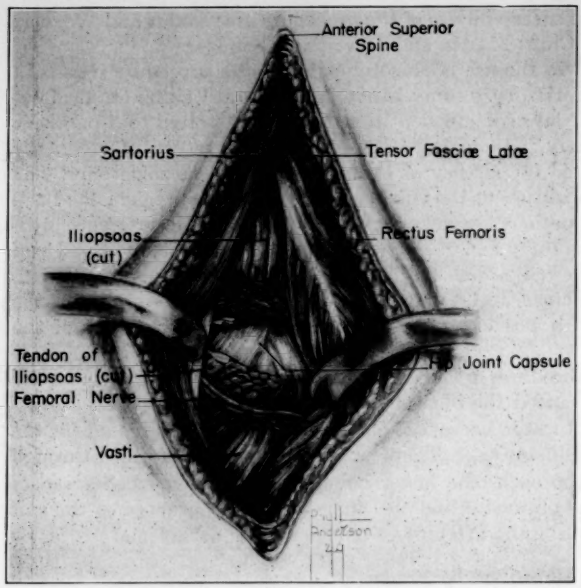

FIG. 1

Operative exposure and section of the iliopsoas.

release of the latter may, in case of incomplete paralysis, permit some return of power in the extensor muscles.

3. By tenotomy of the hip and knee flexors, postural balance tends to be restored in cases with flexion deformity and lumbar lordosis. Following iliopsoas tenotomy, the hip can readily be extended. This procedure also relieves the lumbar lordosis and allows the patient to stand erect. Release of the knee flexors permits full extension for standing with minimum effort or support.

The most important feature of tenotomy in spastic paraplegia is section of the iliopsoas. The tendon of the psoas, which receives nearly all the fibers of the iliacus, is inserted into the lesser trochanter [13]. Below the pelvis no distinct division can be demonstrated between the psoas and iliacus components. The primary action of the iliopsoas is to flex and externally rotate the thigh. When the extremity is fixed, as in standing, the iliopsoas acts to pull the lumbar spine forward. Marked spasm produces flexion of the hip and lumbar lordosis. Between spasms the extemity may relax completely, but, in cases of long standing, part of the de-

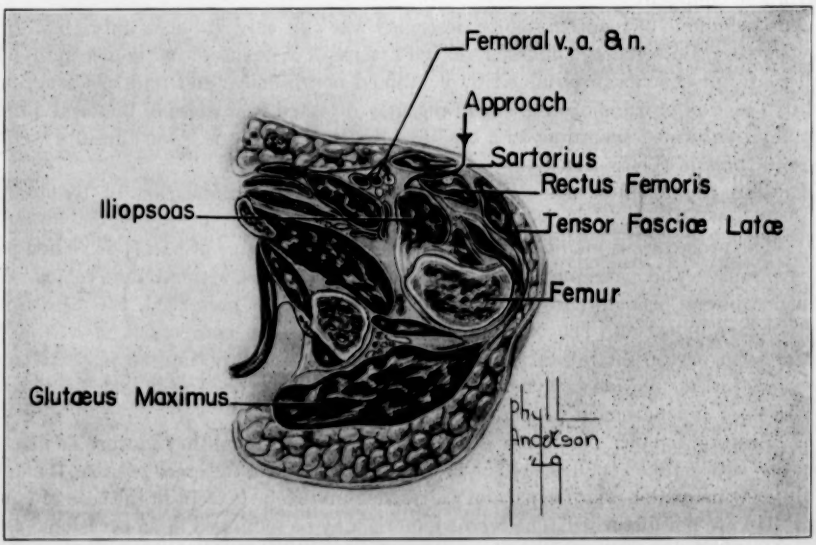

FIG. 2

Cross-sectional view showing the iliopsoas and associated structures.

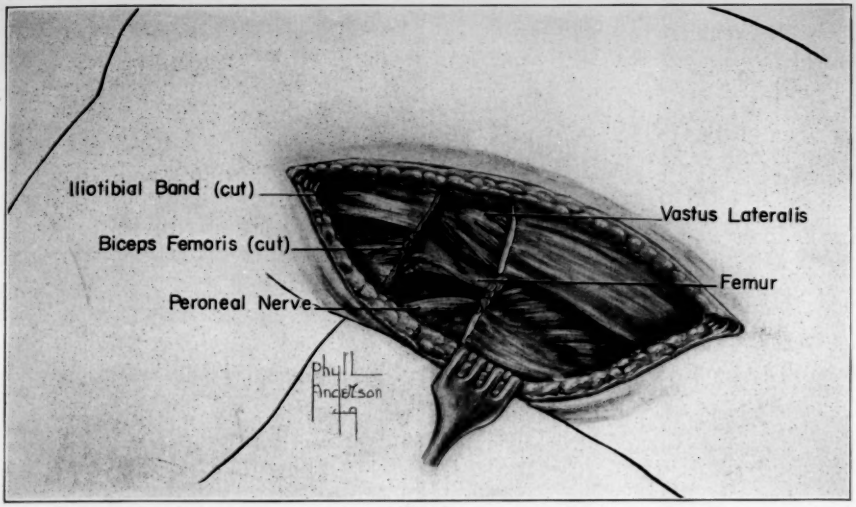

FIG. 3

Operative view showing section of biceps and iliotibial band.

formity becomes fixed. By section of the psoas portion of the iliopsoas, the greater part of the flexor spasm is abolished and all of the lumbar lordosis is overcome, yet a stabilizing effect between the pelvis and femur remains and any residual voluntary action of the iliacus is preserved.

The successful results from partial tenotomy of the iliopsoas indicate that complete tenotomy should not be carried out if there is any voluntary control. Sufficient power still remains after partial tenotomy to flex the hip and lift the extremity from the bed. In complete paralysis, section of the entire muscle is indicated.

Operative Technique

Tenotomy should not be performed until after maximum recovery has taken place, or until exploration of the cord has revealed permanent, complete damage.

Since tenotomies do not restore any power to the paralyzed muscles, the patient should be advised that braces will usually be required to stabilize the knees for standing.

In early cases, care was taken to remove a segment of tendon or muscle to ensure the success of the procedure. In later cases, simple section was considered sufficient, since the proximal portion retracts, due to its spastic nature.

Flexor spasm of the hip is relieved by section of the iliopsoas (Fig. 1). An incision, from four to five inches in length, is made just below the anterior superior spine, separating the sartorius and tensor fasciae latae. The rectus femoris is retracted laterally and the femoral nerve lying on the iliopsoas is liberated and retracted medially, together with the femoral artery and vein (Fig. 2). When paralysis is complete, the entire iliopsoas is sectioned with an electric scalpel just below the head of the femur, the underlying bursa being exposed. When paralysis is incomplete, only the tendon and the medial half of the muscle portion of the iliopsoas are sectioned. It is estimated that the remaining portion, left intact, represents only part of the iliacus.

The adductor spasm of the hip is relieved by intrapelvic or extrapelvic section of the obturator nerve. This procedure is in common use and its technique does not require description.

Flexor spasticity at the knee is relieved by multiple tenotomies of the hamstrings.

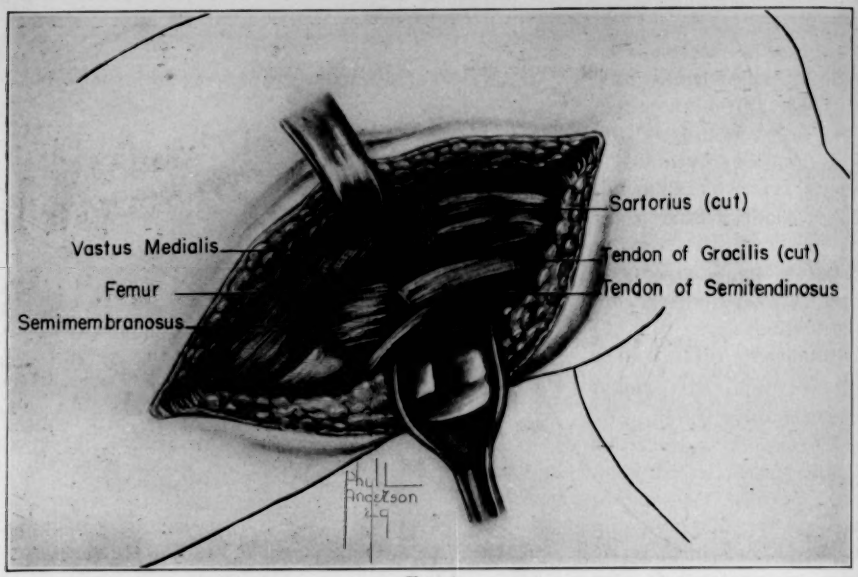

FIG. 4

Operative view showing tenotomies on the medial aspect of the knee.

A two-inch to three-inch longitudinal incision is made on the lateral aspect of the lower thigh, terminating at the level of the knee joint (Fig. 3). When there is a fixed flexion contracture, the iliotibial band is cut transversely to help overcome the deformity; when flexion is due solely to spasticity, section of the iliotibial band is not considered essential. The biceps is exposed and, after identification of the peroneal nerve, the tendon is lengthened in a long Z fashion, when paralysis is incomplete. In complete paraplegia, the biceps is merely sectioned, care being taken to include its muscular portion.

A similar incision is made on the medial aspect of the knee (Fig. 4). The sartorius, which is entirely muscular at this level, is sectioned. The gracilis tendon is then cut although, if obturator neurotomy has been performed, the muscle is already paralyzed. The semitendinosus tendon, which lies just under the skin posteriorly, is similarly sectioned. The semimembranosus, which is composed of muscle and a flat tendinous portion, measures about one inch in diameter and lies deep in the wound, just medial to the popliteal vessels. It may easily be overlooked. When there is some voluntary control, the muscle is left intact; in complete paralysis, the muscle should be completely sectioned. The indication for section of the semimembranosus in complete paralysis is well brought out in Case 7, in which it was necessary to perform a second operation.

If equinus deformity can be overcome by flexion of the knee, indicating that spasticity involves primarily the gastrocnemius, it is customary to section the nerves to this muscle. However, this neurotomy requires the patient to be prone and, therefore, cannot easily be combined with the procedures just described. In a recent case (Case 8), the origins of the gastrocnemius were sectioned through the incisions that had been made to perform the hamstring tenotomies, and the muscle was allowed to retract. The immediate postoperative result has been satisfactory.

Capsulotomy may be combined with tenotomy, when flexion contracture of the hip or knee joint persists after tenotomy. Anterior capsulotomy of the hips was required in only three cases (Cases 1, 2, and 6). If the hips can be extended without capsulotomy, the joint capsule should be preserved, since the mechanism of the paraplegic gait depends upon hyperextension of the hips for stability. In Case 7, it was necessary to perform extensive tenotomies of the leg muscles (Figs. 6-A and 6-B).

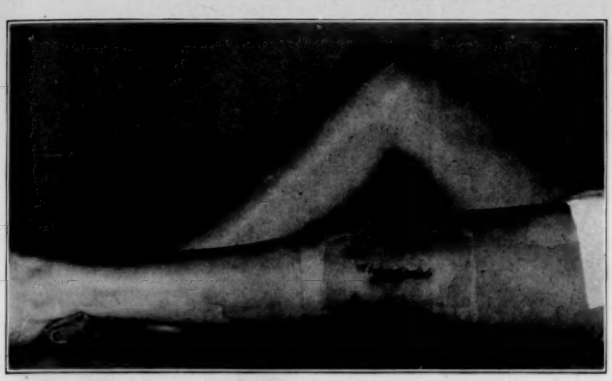

FIG. 5-A

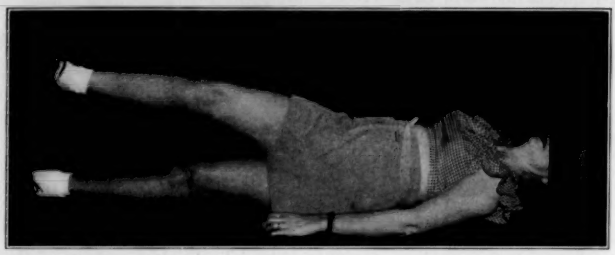

FIG. 5-B

FIG. 5-C

Fig. 5-A: Case 5. Incomplete paraplegia due to fracture of fifth thoracic vertebra. Appearance of the lower extremities a few days after operation on the right side. The hip and knee were in full extension after partial iliopsoas tenotomy and section of the biceps, sartorius, gracilis, and semitendinosus. Preoperatively, both sides were identical and the flexor spasm at the hips and knees prevented ambulation.
Fig. 5-B: Postoperatively the patient was able to lift either extremity from the mat.
Fig. 5-C: Patient was ambulatory without braces and had good voluntary power of hip and knee extension.

Manipulation may be carried out to obtain the last few degrees of extension of the knee. Light, cylindrical plaster casts are advised for a period of from seven to ten days after the operation. In one case, immediately after complete section of the biceps, sartorius, gracilis, semitendinosus, and semimembranosus, there remained temporarily a strong tendency toward flexor spasm at the knee. This was due entirely to the gastrocnemius and occurred only with extensor (dorsal) spasm of the foot. This phenomenon disappeared after a cast had been applied with the knee in extension; and failed to appear on the opposite side, which had been immobilized immediately after operation.

In the first case in this series, bilateral intrapelvic obturator neurotomy and hamstring tenotomy were performed at the first operation. Marked hip flexion persisted, but was completely relieved later by the iliopsoas tenotomy. Usually the iliopsoas and hamstring tenotomies and the obturator neurotomy were done on one extremity, through four incisions, and the other extremity was operated upon a week or two later. The patients were all permitted wheelchair privileges one or two days after each operation.

Advantages of Tenotomy

Tenotomy has several advantages over other forms of surgery for the relief of spastic paraplegia. Tenotomy attacks the reflex arc at an accessible point. Not only is reflex spasm abolished, but also associated deformity may be corrected. It is applicable to cases with partial as well as complete lesions of the spinal cord. Because tenotomy may be selective in its application, it has a particular advantage in cases of flexor spasm with some voluntary power, in which the maximum function must be preserved and postural balance maintained.

FIG. 6-A

Fig. 6-A: Case 7. Complete paraplegia due to myelitis. Preoperative view, showing marked flexion deformity of the hips, knees, and ankles.

FIG. 6-B

Fig. 6-B: Postoperative view, two months after final operative procedure, showing full extension of the hips, knees, and ankles. By using long-leg braces, patient walked very fast with a swing-through gait. Pelvic belt was attached to left side only to control rotation. (*Negative No. 480, Veterans Administration Hospital, Washington, D. C.*)

Reflex activity of the bladder or bowel is not directly altered by tenotomy. However, it is possible that bladder and bowel reflex action may be diminished when spasm of the extremities is relieved. There is not yet sufficient proof that tenotomy has a beneficial effect on the bladder and bowel, and further evaluation of the procedure will be necessary in this respect.

REPORT OF CASES

In this series of ten cases, paraplegia was due to trauma in three, to multiple sclerosis in three, and to myelitis in four (Table I). The paraplegia was complete in five and incomplete in five cases, but only two of the latter had voluntary power of a useful degree. There were six males and four females; their ages ranged from twenty-one to fifty-eight years, with an average age of forty. The illness varied from four to twelve years, with an average duration of 6.6 years. All of the patients had flexor spasm, which was considered severe in seven and moderately severe in three. Seven had adductor spasm of varying degree which required obturator neurotomy; one of these had previously had nerve crushing which offered temporary relief. One additional patient had previously had bilateral neurotomy, and two did not require correction of adductor spasm. In seven cases the spasticity was almost constant; in all, it severely interfered with rest and prevented ambulation and successful rehabilitation.

Ten operations for exploration or therapy had been carried out previously on nine of the ten patients. Six patients, including the three in which the condition was due to trauma, had undergone exploratory laminectomy in the cervical or thoracic region. One patient had had posterior rhizotomy without benefit. Bilateral obturator neurotomy had been done in one and bilateral obturator-nerve crushing in another. One patient with myelitis attributed to vascular disease had bilateral lumbar sympathectomy. The pain associated with flexor spasm was so severe that lobotomy had been proposed for relief.

In this discussion the term tenotomy refers also to myotomy, where the latter may apply. Partial tenotomy of the iliopsoas was performed in eight extremities, complete tenotomy in nine. In six hips subjected to complete iliopsoas tenotomy, wide anterior capsulotomy was also performed. In the first two patients of the series, both of whom had

TABLE I

FINDINGS IN TEN CASES

Case	Age	Etiology	Duration of Disease (*Years*)	Degree of Paralysis	Degree of Spasticity	Previous Operations	Surgery			Results
							Iliopsoas Tenotomy	Hamstring Tenotomy	Obturator Neurotomy	
1 R. S.	29	Multiple sclerosis	5	Complete, twelfth thoracic	Severe	Laminectomy	Bilateral *	Bilateral	Bilateral	Excellent
2 C. McC.	21	Gunshot wound	7	Complete, seventh thoracic	Severe	Laminectomy	Bilateral *	Bilateral		Excellent
3 E. V.	58	Myelitis?	6	Incomplete	Moderately severe	Sympathectomy	Unilateral *	Bilateral		Very good
4 S. M.	26	Myelitis	4	Complete, sixth thoracic	Moderately severe	Obturator-nerve crushing	Bilateral *		Bilateral	Excellent
5 A. D.	40	Fracture	4	Incomplete, fifth thoracic	Severe	Laminectomy, obturator neurotomy	Bilateral **	Bilateral		Excellent
6 M. B.	46	Multiple sclerosis	9	Incomplete	Severe	None	Bilateral *	Bilateral	Unilateral	Poor
7 M. P.	33	Myelitis	4	Complete, first lumbar	Severe	Laminectomy	Bilateral **	Bilateral	Unilateral	Excellent
8 J. K. H.	51	Myelitis	9	Incomplete, seventh thoracic	Severe	Laminectomy	Bilateral **	Bilateral	Bilateral	Very good
9 H. S.	57	Fracture	12	Complete, seventh cervical	Moderately severe	Laminectomy		Bilateral	Bilateral	Excellent
10 B. McG.	43	Multiple sclerosis	6	Incomplete	Severe	Posterior rhizotomy	Bilateral **	Bilateral	Bilateral	Excellent
Totals						10	17	18	12	

* Complete section of iliopsoas. ** Partial section of iliopsoas.

complete lesions, the rectus femoris and the sartorius were sectioned bilaterally at their points of origin, but this is probably not necessary unless there is marked contracture of long standing. Only one patient, with a complete lesion of the lower cervical region, had paralysis of the upper extremities. His sleep was constantly interrupted and he was always fearful of falling out of bed during the spasms of the lower extremities. He obtained complete relief by obturator neurotomy and hamstring tenotomy; section of the iliopsoas was not required. Only one patient did not require tenotomy of the knee flexors, but he had iliopsoas tenotomy, obturator neurotomy (the nerve had previously been crushed), section of nerves to the spastic gastrocnemius on one side, and lengthening of a contracted, nonspastic Achilles tendon on the other side. In three patients with incomplete lesions the semimembranosus was left intact.

RESULTS

In nine of the ten patients the result is considered excellent or very good after a period of from six to thirty months. Six are able to be up in braces with the usual limitations due to paraplegia. One patient (Case 8) walks a little without braces, using a walker or parallel bars. Two walk with canes, without brace or crutch. One of the latter (Case 5) (Figs. 5-A, 5-B, and 5-C) is especially noteworthy, since the patient is quite independent as a housewife after bilateral obturator neurotomy, partial iliopsoas tenotomy, and hamstring tenotomy (except for the semimembranosus). Case 6 is considered unsuccessful; this was a patient with multiple sclerosis who suffered extreme intermittent flexor and adductor spasms. The spasms were completely relieved after operation and she had marked improvement in her comfort, her general condition, and her personality. However, after six months, marked extensor rigidity of the spine and lower extremities developed with general progression of her disease, loss of weight, and decrease in bladder and bowel function. In this case anterior rhizotomy, producing complete flaccidity, would have given more relief. As yet, none of the other patients has shown any increased tendency to extensor spasm. There were no deaths, no surgical infections, or other complications.

CONCLUSIONS

A method of treatment, proposed for the correction of severe flexion deformities in spastic paraplegia, consists of multiple selected tenotomies, combined with neurotomies as indicated. Paraplegia with severe flexor spasm presents essentially a combination of hip flexion, hip adduction, and knee flexion. Hip flexion can be relieved by section of the psoas and, in the complete lesions, more easily by complete iliopsoas tenotomy; hip adduction can be relieved by extrapelvic obturator neurotomy; knee flexion can be relieved by hamstring tenotomy, with preservation of the semimembranosus in some cases where the lesion is incomplete.

The flexor spasm was relieved in each of the ten cases presented, but severe extensor rigidity later developed in one. Treatment by tenotomy is selective in scope, does not interfere with visceral function, and is safe in the presence of debility or decubitus ulcers. All patients require extensive physical therapy and rehabilitation after operation, and in most cases braces are required. Destructive surgery is indicated only after maximum recovery has occurred and after more conservative measures have failed.

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DISCUSSION

Dr. Arthur S. Abramson, White Plains, New York: Dr. Peterson has made a definite contribution by bringing to our attention a procedure for the treatment of spasticity which is effective and yet is limited in its destructiveness. In our experience, also, tenotomy and neurotomy have given satisfactory results. Since tenotomy is not a new procedure, it is hard to understand its lack of popularity in the treatment of spasticity in the adult.

Spasticity *per se* is not necessarily a bad thing. It can be considered the method by which the organism protects itself against noxious stimuli, maintains bulky pads of muscle capable of resisting pressure, and

increases blood flow as a result of the metabolic demands of involuntary muscle action. Unfortunately, it is often severe enough to make the patient incapable of coming to terms with his environment, either mentally or physically. In such cases, a procedure which limits the severity of the spasticity, but does not erase it completely, is rational. Before any operative procedure is carried out, all irritative foci, such as urinary stones or infection, should be eliminated.

Even more limited procedures than those described by the author may be effective. Spasticity, except in certain limited instances, is not entirely a mass reflex. There is also a circulating chain of reflexes following certain patterns, a product of nociceptive or proprioceptive stimuli. The nociceptive stimulus usually comes first and is limited in time. The result of this stimulus is probably a contraction of limited scope. It is the flood of afferent stimuli arising from the contracting muscle which extend the amplitude and duration of the spastic response. From this concept, it would appear that a reduction in the afferent inflow to the cord should materially reduce the degree of spasticity generally, as well as eliminating it in the muscle which has had tenotomy.

There is some evidence for this concept. Besides tenotomy of the more excessively reacting muscles, neurotomy and posterior rhizotomy may also effectively block off the quantity of afferent energy. After careful clinical observation of many cases of spasticity, it becomes obvious that frequently the adductor muscles may respond early and excessively to a stimulus. In these cases, adductor tenotomy or obturator-nerve section is usually adequate. This procedure is not particularly destructive, even in an incomplete lesion. Other muscle groups may be the excessive reactors and the treatment may be approached from the same point of view.

In one case, denervation of the calf muscles and hamstring tenotomies were sufficient to relieve hip and knee flexion spasticity. Adductor spasticity was not the primary problem in this instance. The patient had severe flexion contractures of the hips as well as of the knees. The operative procedures reduced the total spasticity so that the hip flexion contractures, which did not previously respond to conservative treatment, could be easily stretched by means of physical therapy. The patient, whose lesion was markedly incomplete, was able to walk very well following the procedure. It is doubtful whether such an excellent gait would have resulted had the power of the hip flexors been reduced by tenotomy. This case also demonstrates clearly the principle that it is extremely hard to evaluate the degree of contracture or the amenability to stretching in the presence of severe spasticity.

In order to evaluate carefully the results that could be obtained by denervating or tenotomizing a muscle, selective nerve blocks are done. It is likely that the best results can be obtained when interference with the neuromuscular system is bilateral and symmetrical. Anterior rhizotomies are occasionally incomplete, due to technical difficulties in identifying the roots correctly. The asymmetry in remaining spasticity may produce a pelvic tilt with marked lumbar scoliosis. In one case with a high cord lesion and a mid-thigh amputation on one side, a similar picture was seen. The quantity of stimuli coming from the amputated side were reduced because of the loss of a large mass of contracting muscle. The spasticity of the trunk and extremity muscles on the unamputated side was much greater and probably produced the deformities mentioned. In another case of a high cord lesion with fusion of the hip on one side, due to soft-tissue ossifications, the same deformities were also observed. Because of the inability of the hip muscles on the fused side to shorten, it must be assumed that atrophy occurred and a source for afferent stimuli was lost to the body asymmetrically.

These cases demonstrate two principles. First, there is a reduction of spasticity as a whole, even with limited interference of the neuromuscular system. Second, the reduction of spasticity is unilateral where there is unilateral interference with the neuromuscular system. Of course, we are in no position to state that these principles are always true. Many patients will require all the procedures described by Dr. Peterson. Results have shown that, in some cases, much less will be adequate. Perhaps steplike stages with conservative therapy in the intervals will reduce the amount of surgery necessary to obtain a satisfactory result.

I have had the opportunity of observing at least one of Dr. Peterson's cases and I was impressed with the results. The patient was a young girl whose spasticity had been so markedly reduced by the procedure as to permit her to walk great distances with crutches and braces.

DR. HAROLD A. SOFIELD, CHICAGO, ILLINOIS: The tenotomy procedures outlined by Dr. Peterson undoubtedly have a prominent place in the treatment of spastic deformities, whether they are associated with the common types of traumatic paraplegia or are complications of cerebral palsy.

At Hines Veterans Hospital, all of these procedures are used in selected cases of paraplegia, although tenotomy of the iliopsoas has been carried out infrequently and probably should be done more often. In our Crippled Children's Hospital, iliopsoas tenotomy has been employed occasionally and has a definite place in our armamentarium. Our work varies only in a few details from that presented by Dr. Peterson. We prefer the intrapelvic approach rather than the extrapelvic approach for obturator-nerve section, and our approach for iliopsoas tenotomy varies somewhat from that outlined in the paper.

Dr. Peterson deserves commendation for assembling a good group of cases and for emphasizing the use of procedures found to be of value.

BLASTOMYCOSIS OF BONE

Report of a Case

BY KARL S. ALFRED, M.D., AND MAXWELL HARBIN, M.D., CLEVELAND, OHIO

From the Division of Orthopaedic Surgery, Department of Surgery, University Hospitals, Cleveland

Mycotic infection of bone, although not encountered frequently in orthopaedic surgery, must be seriously considered in those cases of infection which do not lend themselves to ready diagnosis.

Of the various fungous infections which may involve bone, the two diseases termed blastomycosis and coccidioidomycosis are by far the most prominent and the most serious. Carter and others have stated that the first case of coccidioidomycosis was described by Wernicke in 1892. Gilchrist, in the last part of the nineteenth century, discovered blastomycosis, often called Gilchrist's disease. The term means "budding" and is a misnomer, for this characteristic is common to many types of fungi besides blastomycosis. *Coccidioides immitis* received its name from the similarity of the organism to the protozoan group; the early investigators thought they were dealing with a protozoan infection. In 1900, Ophüls and Moffitt proved it to be a pathogenic mold.

PATHOGENESIS

The source of these infections is usually the soil, which sends up delicate spores, breaking free from aerial hyphae and so light that they may easily float in the air[2]. The portal of entry is usually through the lungs by inhalation of these spores, although a physician has been known to have acquired blastomycosis following a laceration received while performing an autopsy [9]; and a case was reported in which a nurse with a cutaneous lesion on her arm transmitted the disease to a child she was tending. There are two phases in the life cycle of these organisms, one vegetative and one parasitic. The parasitic phase occurs in the body of an infected host.

After inhalation of the spores of coccidioidomycosis, reproduction occurs within the tissues by rupture of the wall of the spore or mother spherule, with release of many endospores. These endospores closely resemble cocci and hence gave the disease its name. In blastomycosis, however, reproduction within the tissues is never by endosporulation, but always by budding, and this is an important diagnostic point.

SYMPTOMATOLOGY

The onset of the disease may be insidious and infection may be widespread before the condition is finally diagnosed, a subacute primary respiratory infection having gone unnoticed. Coccidioidomycosis is endemic in the Southwest, especially in the San Joaquin Valley of Southern California [3]. It is the more prevalent of the two diseases. Most of the residents of the Southwest have had a primary coccidioidal infection and an immunity has developed[3]. After this apparently benign upper-respiratory infection, there follows an incubation period of about three weeks; thereafter acute pneumonitis may develop, which usually heals with fibrosis and occasionally with cavitation. Its relationship to a fungous infection is generally not recognized, and it is diagnosed as "influenza" or pneumonia. About 2 to 5 per cent. of those who have had respiratory symptoms demonstrate clinically an "allergic reaction" two to twenty days later, characterized by fever, arthritis, and muscle pains. Joints are tender, painful, and slightly swollen, but no effusion occurs, and after about one month the symptoms disappear without articular residue. In the vast majority of cases nothing further develops, but in about 0.05 to 0.3 per cent. the infection

becomes systemic, a progressive "secondary" granuloma. Depending upon the site or sites to which the fungus spreads, granulomatous lesions occur in soft tissues, bones, or parenchymatous tissues, commonly affecting the meninges, bones, joints, muscles, skin, et cetera. Such is the course of coccidioidomycosis.

The blastomycosis we see is a North American disease, but is not endemic anywhere. It has an even more insidious onset than coccidioidomycosis. After a period of weeks or months following the unrecognized primary respiratory infection, the patient begins to have a low-grade fever, loses weight and strength, and has night sweats. A skin ulcer or subcutaneous abscess is often the first symptom suggesting fungous disease. The lesion starts as a soft subcutaneous nodule, and the overlying skin has a dusky erythematous hue. Such nodules tend to break down and discharge sanguinopurulent material. After rupture, the abscesses may heal, leaving dense depressed scars, or may develop into chronic progressive ulcerative lesions. If a subcutaneous abscess is formed by extensions from an infected bone, a chronic discharging sinus may develop and may persist for months or even years. Blastomycosis or coccidioidomycosis should be suspected, if chronic discharging sinuses or subcutaneous abscesses are present over varying parts of the body. The disease must be differentiated from tuberculosis, syphilis, neoplasm, lung abscess, sarcoidosis, silicosis, osteomyelitis, psoas abscess, actinomycosis, histoplasmosis, sporotrichosis, and moniliasis.

ROENTGENOGRAPHIC APPEARANCE

Roentgenographically, the bone lesions of coccidioidomycosis and blastomycosis are identical and cannot be distinguished. The lesions usually arise in cancellous bone and are predominantly destructive with little or no periostitis, bone production, or marginal reaction. A distinctive, clear-cut area of complete bone destruction is seen by roentgen ray. The most difficult differentiation is tuberculosis; however, there is only infrequent joint involvement and then by a process of extension, whereas in tuberculosis the joints are involved early and by selection. Metastases, myeloma, syphilis, sarcoma, and bone cyst may give somewhat similar roentgenographic pictures, but are not so confusing as tuberculosis. According to Carter, lesions directly suggestive of mycotic infection of bone include:

1. Those arising at such points of bony prominence as poles of patellae, acromion, coracoid processes, angles of scapulae, olecranon, styloid processes of radius and ulna, condyles of humeri, or extremities of clavicles.
2. Lesions of malleoli.
3. Lesions arising in tuberosities of tibiae.
4. Marginal solitary lesions of ribs.
5. Localized destructive lesions of the outer table of the skull.
6. Destructive lesions of vertebrae, attacking indiscriminately body, processes, or neural arches.

As in tuberculosis, the lesion is a solitary lesion of spongiosa, predominantly destructive, with little tendency to heal by bone production, and is frequently associated with pulmonary involvement. However, the infection in bone is usually more rapid in onset and development, and so shows less atrophy of adjacent bone.

PATHOLOGICAL CHANGES

Pathologically, the disease is a granuloma, similar to tuberculosis and other granulomata. The submiliary, miliary, or larger nodules closely resemble tubercles. These may caseate. Later the caseous material may liquefy and cavities containing puslike material may be produced, or suppuration may occur from the beginning. Suppuration may be acute, but is usually chronic, leading to abscesses and ulcers. Lesions are nearly always progressive with a marked tendency to dissemination by lymph and blood stream, but they sometimes heal.

Cutaneous involvement may occur as nodes or papular eruptions, with or without ulceration, and as evacuating sinuses of deeper abscesses. Abscesses may occur in the subcutaneous tissues. Lymph glands may be involved early and extensively with caseation and suppuration.

Lesions of bone are essentially in the form of destructive osteomyelitis, arising either centrally, subperiosteally, or by extension from adjacent abscesses.

DIAGNOSIS

Once one has become suspicious of a mycotic infection, the diagnosis can be absolutely substantiated by direct examination of material obtained from cutaneous lesions or by aspiration. The material is examined microscopically by mounting a loopful in a drop of saline in 10 per cent. potassium hydroxide and adding a cover glass. Blastomycosis appears in the preparation as single or budding spherical cells, yeastlike bodies. The walls of these cells are so thick that they are very refractile and form a "double-contoured" appearance in fresh preparations. Coccidioides are uniformly larger, non-budding, and may contain spherules. Their walls are also very refractile.

Infected material may also be cultured on Sabouraud's medium, and in ten to forty days it will give a white cottonish aerial growth which becomes tan to brown with age.

Animal inoculation usually is not necessary. If done, however, typical lesions develop in mice in three weeks with gross infection in the liver, spleen, lungs, and lymph nodes.

A skin test may be performed with specific vaccine, but this is used more as a sensitivity test than a diagnostic measure.

PROGNOSIS

The prognosis in these diseases is uniformly bad [4, 13]. In their review of the literature on blastomycosis, Martin and Smith noted a mortality rate of 92 per cent. in patients who had been followed for two years or longer.

TREATMENT

There is no known remedy and treatment is largely supportive. Penicillin, streptomycin, sulfonamide drugs, and other forms of specific therapy have all proved futile. Continued treatment with saturated doses of potassium iodide has given the best results, and is the most highly recommended form of treatment. However, this may have adverse effects, and Martin cautions that, before beginning iodide therapy, patients should have skin tests and be desensitized by increasing vaccine injections if they react positively to the vaccine. Apparently the only hope in these cases is continued use of iodides, for years if necessary, and frequent courses of vaccine therapy.

There have been favorable reports from deep roentgenotherapy of cutaneous and well localized lesions, and this is certainly worth a trial in some cases. Amputation is justified, and is indicated in well localized lesions of the extremities.

CASE REPORT

Mrs. D. K., a white woman, twenty-seven years old, was first admitted to University Hospitals on June 1, 1948. She was a native of Cleveland, but had been living in Alabama for two years prior to admission. The patient had traveled through the Southwest, including Southern California, on the way to her new home in Alabama. Just a few weeks after her arrival, in May 1946, she had noticed a somewhat painful lump in her left hip. There had been no prodromal symptoms or trauma, and her general health had been good. However, she had a daily low-grade elevation of temperature and had lost about fifteen pounds in weight. This painful mass persisted, but was not aggravated by walking and there was no radiation of pain. After two months, a small fluctuant mass appeared over the lateral uppermost aspect of the left thigh. This was lanced as an ordinary "boil" by her local physician. Two more months passed and a tender mass appeared in the upper lateral quadrant of the left buttock. At this time roentgenograms were taken, which revealed a destructive process in the left ilium near the sacro-iliac articulation.

She was then referred to an orthopaedic surgeon in Alabama, who found her to be running a low-grade fever and walking with a limp which involved the left lower extremity. There was a mass in the left buttock, over the area of the sacro-iliac joint, but no neurological findings. There was tenderness over the left ilio-lumbar triangle and a small draining sinus on the lateral aspect of the left thigh, in the region above the trochanter.

Laboratory studies at this time showed normal blood count, blood chemistry, and serology, but a sedimentation rate of 98 millimeters per hour. The tuberculin test and guinea-pig inoculation of material from the sinus were negative for tuberculosis. Attempts to aspirate the mass in the left buttock gave a seropurulent type of material which brought a negative result from the laboratory, including study for tuberculosis, gonococcal infection, and syphilis.

In the absence of positive laboratory findings, but because of the persistence of clinical signs and roentgenographic evidence, the left sacro-iliac joint was exposed surgically. Pus was evacuated and a portion of the joint was resected. The patient felt better for several months, although a persistent draining sinus developed in the operative area. She was kept in bed with occasional trials of both traction and a hip spica, but there was no change in her condition.

In May 1947, about one year after the onset of her symptoms, a wide excision of the diseased area was recommended. Accordingly, this was done and thick purulent and granulomatous tissue was evacuated. It was the surgeon's opinion that this was coming from the retroperitoneal glands of the abdomen and that it was tuberculous in nature. The pathologist's report tended to substantiate this, although no definite diagnosis was made from a pathological standpoint.

From then until the time of her admission to University Hospitals, the patient was treated by bed rest, supportive measures, including all kinds of vitamin preparations, multiple whole-blood transfusions, a total of 27,000,000 units of penicillin, 280 grams of streptomycin, and 1,000 grams of sulfadiazine.

Despite these expensive and heroic measures, her lesion progressed. The patient had been bedridden for almost two years, had undergone two extensive exploratory operations, and had been subjected to all forms of chemotherapy.

Upon admission to University Hospitals, the patient's temperature was elevated daily to 38.5 degrees centigrade; the pulse remained consistently around 100; and the blood pressure was 108 systolic and 60 diastolic. There were multiple draining sinuses of the left buttock and thigh with deep postoperative scars (Fig. 1). There was also a mass in the left vulva, resembling a Bartholin cyst, and a glandular breakdown in the left groin with suppuration (Fig. 2). There was a 20-degree flexion contracture of the left hip, which was corrected by traction and physical therapy.

The laboratory examinations were as follows: The urine was slightly hazy; the specific gravity was 1.009, with alkaline reaction; it contained no albumin or sugar. The microscopic examination of the urine revealed only an occasional white blood cell.

The blood examination showed:

Red blood cells	4,100,000
Hemoglobin	70 per cent.
Hematocrit	42 per cent.
White blood cells	13,850
Segmented neutrophils	58 per cent.
Unsegmented neutrophils	5 per cent.
Lymphocytes	26 per cent.
Monocytes	9 per cent.
Eosinophils	2 per cent.

The sedimentation rate (Wintrobe method) was 33 millimeters in one hour. The serum total-protein determination was 6.7 grams, albumin 4.3 grams, and globulin 2.4 grams per 100 cubic centimeters. The serology was negative and the tuberculin test, in a dilution of 1 to 10,000, was negative. Agglutination tests for typhoid, paratyphoid, *Brucella abortus*, and Proteus OX19 all were negative. Cultures from the suppuration in the groin and from material drained from the many sinuses showed hemolytic and non-hemolytic *Staphylococcus aureus* on blood glucose agar.

Roentgenograms revealed an irregular, four-centimeter hole in the posterior portion of the left innominate bone, just above the sacro-iliac joint. The margins of the bone defect were sharp and there was practically no osteoporosis of the surrounding bone. A similar area of bone destruction, with no surrounding reaction, was seen in the left ischial tuberosity (Fig. 3). The roentgenographic examination of the chest was normal.

The tuberculin test being negative, it was obvious that we were dealing with some unusual infectious process. Many smears were made of the material obtained from the glandular breakdown in the groin. All of these showed numerous yeastlike cells of different sizes with a double-contoured refractile wall, which we determined to be the typical organism of blastomycosis. A specimen for biopsy was obtained from the margin of the ulcer in the groin, and this amply substantiated the diagnosis. In addition, a culture obtained at the time of admission and planted on Sabouraud's medium resulted in a profuse growth of the hyphae-like mold characteristic of blastomycosis and coccidioidomycosis.

FIG. 1

FIG. 2

Fig. 1: This shows the many draining sinuses and deep postoperative scars of the left buttock and thigh. Upon irrigation of the ulcerated area in the left groin, copper sulfate solution was found to drain through all of these sinuses, indicating intercommunication of all of them and through-and-through drainage anteriorly to posteriorly.

Fig. 2: This shows the area of glandular breakdown in the left groin. All smears made from material from this ulcer revealed an abundance of organisms. The biopsy specimen was taken from the wall of the ulcer.

FIG. 3

Roentgenogram showing the lesions in the left ilium and left ischium. Note the complete destruction, absence of any bone production, and almost complete absence of surrounding atrophy.

Because of the grave prognosis, the patient was immediately started on increasing doses of 50 per cent. potassium iodide by mouth three times daily, plus supportive therapy. Despite the fact that she was still having a low-grade fever and had not walked for almost two years, attempts at ambulation were begun.

Vaccines of both blastomycosis and coccidioidomycosis were obtained.* The patient gave a markedly positive reaction to blastomycosis and a negative reaction to coccidioidomycosis. Desensitization procedures were then begun. Starting with a 1 to 100 dilution of vaccine, the patient was given a subcutaneous injection of Blastomyces vaccine three times weekly, the initial dose being 0.1 cubic centimeter. Each succeeding dose was increased by 0.1 cubic centimeter until 1.0 cubic centimeter was reached. Then a similar procedure was done with a 1 to 10 dilution of vaccine, followed by similar injections with the full-strength vaccine. The patient thus received a total of thirty injections.

After the first two weeks in the Hospital, the patient began to show improvement. The drainage from her many lesions diminished, her temperature and pulse rate began to approach normal, and she was soon walking. She was discharged on the twentieth hospital day and was followed in the Out-Patient Department three times weekly until the course of vaccine had been completed. When the maximum dosage of iodides was reached, forty-five drops of 50 per cent. potasssium iodide three times daily, this was maintained and the patient was considered well enough to rejoin her husband in the South. She was next seen in December 1948, just six months after her discharge from the Hospital. She had gained twenty-five pounds in weight and there was practically no drainage from the lesions. She was still on high daily doses of potassium iodide, showed no signs of iodism, and was leading a normal life.

Unfortunately, this excellent response to treatment was only temporary, for in April 1949 she returned to Cleveland, complaining of profuse drainage, low-grade fever, anorexia, malaise, and weight loss. There was a new area of induration over the sacrum and the left ischium, which made it both painful and difficult for her to sit. Attempts at aspiration of this mass were unsuccessful. The patient was showing some signs of chronic iodism, and so iodides were discontinued. More or less as a last resort and because it had not been done previously, a course of deep roentgenotherapy was started over the involved areas. The profuse drainage persisted, however, and she continued to have daily fever.

The patient returned to Alabama in June and was last heard from in September 1949, at which time there was still profuse drainage and she was receiving another course of deep roentgenotherapy.

* Through the courtesy of Donald S. Martin, M. D., Duke University.

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SKELETAL CHANGES IN SICKLE-CELL ANAEMIA

Report of an Unusual Case

BY ALLEN E. HAMBURG, M.D., ATLANTA, GEORGIA

From the Department of Orthopaedic Surgery, Lawson Veterans Hospital, Chamblee, Georgia

This paper contains a review of the literature dealing with the skeletal changes in sickle-cell anaemia, and adds a case which presented a diagnostic problem.

Sickle-cell anaemia, originally described by Herrick in 1910, is to be distinguished from the sickle-cell trait unaccompanied by anaemia [25]. The chronic hemolytic anaemia is transmitted as a Mendelian dominant characteristic, which occurs almost exclusively in the negro. Moore reported skeletal changes in Mayan and Peruvian Indians, suggesting that this is an ancient and widespread disease. It has since been reported in other races, including the white race [7,6,20,37]. In sickle-cell anaemia, as in erythroblastic anaemia and chronic hemolytic jaundice, abnormal erythrocytes are generated by the blood-forming tissues. Characterized by periods of exacerbation and quiescence, the disease typically presents anaemia, leg ulcers [22], abdominal and joint pains [5,24], splenomegaly, apical systolic murmurs [17], fever, and leukocytosis in children. Usually a diagnosis is easily made, and can be confirmed by examination for the sickle-cell trait in a specially prepared blood smear [4,33]. Resistant to therapy, the condition is frequently fatal in childhood [1] due to intercurrent infection, but not uncommonly the course is sufficiently mild so that the individual may survive adolescence. Few patients survive into the sixth decade, as did the man whose case is reviewed in this paper.

Familiarity with the pathophysiology of the disease aids one in anticipating the skeletal changes. It has been shown that sickling is an inherent property of the red blood cells, and is precipitated by alterations in the ratio of combined to dissociated hemoglobin. A diminution in the oxygen tension, by increasing the amount of reduced hemoglobin, results in sickling [32]. A rise in the oxygen tension causes the cell to assume its normal shape. Sickled cells are rigid cells which result in capillary blockade. The widespread changes found in the various organs in this disease are due to thromboses which form from the rigid sickle cells in the capillaries and rapidly ascend to larger vessels [36], particularly on the arterial side. A direct relationship has been shown [32] to exist between the age of the cell and its tendency toward sickling. It is now postulated that a crisis occurs, due to widespread thrombosis, as the capillaries become jammed with deficiently oxygenated sickle cells. As a result, widespread symptoms become manifest. Following a crisis, there is sharp fall in the red-blood-cell count, with a stimulus for the bone marrow to become hyperplastic and produce a new generation of cells which will ultimately have the same fate as the previous generation. Whereas in non-hematopoietic tissues the pathological changes are essentially those of congestion and thrombosis [29], the bones show a combination of these changes and those of bone-marrow hyperplasia.

The effort of the hematopoietic tissues to maintain adequate circulating blood elements is reflected in the bone marrow, where normal resting yellow marrow is converted into congested, highly cellular, red marrow [18]. This hyperplasia may occur in virtually any bed of cancellous bone, but it is more marked in the calvarium, the long bones, and the bones of the trunk. Whereas these changes may be found in any form of hyperplastic anaemia [23], in sickle-cell anaemia there are, in addition, varying degrees of thrombosis and infarction which with time result in hyalinization, fibrosis, abnormal calcification, and new-bone formation.

Graham, in 1924, was the first to report a pathological study of the bone changes in this disease. He reported that the picture is essentially that of a chronic infectious or

toxic injury of the marrow tissue and medullary bone, with subsequent repair processes and compensatory hyperplasia. There is focal necrosis, destroying the soft tissues and injuring the bone trabeculae. The necrotic marrow is replaced by loose granulation tissue; bone repair is also in evidence. At times the new-bone formation proceeds so far as to narrow, distort, or even destroy the original marrow cavity.

Diggs, Pulliam, and King noted that this is the picture of osteosclerosis in late disease in a patient thirty years of age. These writers, in a study of eight necropsies, made several important observations on bone structure in this disease. They concluded that the long bones are of normal size and external appearance although, in old cases with leg ulcers, the leg bones may show roughening and periosteal new bone. The cortical thickness varies considerably, but tends toward increased density and thickening, even to the point of complete obliteration of the marrow cavity. Marrow hyperplasia, found even in the Haversian canals, is more marked near the medullary cavity and gives rise to a honeycomb appearance by roentgenogram. New-bone formation usually takes the form of linear trabeculae, but sometimes there are layers of lamellated bone, paralleling cortex or sheaths perpendicular to cortex.

The reports in the literature concerning the roentgenographic changes seen in this disease are conflicting, so that it has been difficult to establish the characteristic lesions. The roentgenographic picture may vary from entirely negative findings in a complete bone survey to extensive osteoporotic and osteosclerotic changes.

Cooley, Witwer, and Lee, in 1927, were the first to report roentgenographic observations in this disease, but Rose was apparently the first to note abnormal bone changes. The early reports [9,21,26,28,30,34,35] focused attention on the skull which was presumed, in typical cases, to show thickening of both tables; this was associated with spicules of bone radiating perpendicular to the flat bone to give the "hair-on-end" appearance [13] with loss in definition of the outer table. The thickening and striation have usually been most marked at the vertex, but may involve to a lesser extent the frontal and occipital bones. Grinnan, Borzell, Vogt and Diamond, Cooley and Lee, and others have called attention to the similarity of the changes in this disease with those of erythroblastic anaemia. The chief point in the differential diagnosis from a roentgenographic viewpoint is that sickle-cell anaemia presents maximum thickening of the vertex, whereas erythroblastic anaemia presents maximum thickening in the frontal and occipital regions. Cooley and Lee, in a study of thirty cases of latent sickle-cell anaemia, found only one patient showing skeletal changes; in that case the changes were similar to those of erythroblastic anaemia. More recent reports by other authors confirm that most patients do not show skeletal changes, and that, even if they be present, they are not of positive value in differential diagnosis. Caffey found thickening of the calvarium in two-thirds of a group of fifteen patients, but none showed radial striation or atrophy of the outer table. Several authors have warned that the skull thickening must be differentiated from that due to rickets. Since the finding of vertical striations is actually noted in only a small percentage of cases, regardless of the severity of the disease, it is of limited diagnostic value. Experienced roentgenologists do not make a definite diagnosis from this finding alone. Many authors have found entirely negative roentgenograms in various age groups with all degrees of anaemia.

The bones of the trunk are apparently among the last bones to show roentgenographic changes. Again it is bone-marrow hyperplasia which results in osteoporosis, producing both diffuse and localized areas of radiolucency. Osteosclerosis develops gradually over a period of many years and is less commonly seen. The most notable findings in the trunk bones are usually increased radiability and flattening of the lumbar vertebrae, and increase in the striations in the ribs.

Machado and Corrigan and Schiller were among the first to report indefinite abnormalities of the long bones in this disease. Graham, in his detailed pathological study, reported reduction in size of the medullary cavity of the femur, due to an inward over-

growth of cortical bone. Moore [30] noted that the changes in the long bones were the opposite of those seen in erythroblastic anaemia. He, too, found inward thickening of the cortex, and even complete obliteration of the medulla in the phalanges. These findings coincide with Graham's description of the anatomical changes. Caffey, in a detailed study of the long bones in fifteen patients, found no abnormalities attributable to the disease. However, the oldest patient in his series was fifteen years of age. In Cooley and Lee's thirty cases of sicklaemia, with or without anaemia, the long bones were normal. Grinnan described peculiar striations in the long bones, usually near the ends of the shafts, with thinning of the cortex at the distal ends, in a patient four years of age. Brandau found decreased density and splotching of the medullary portion in the tibia and fibula of a negro, twenty-two years old. Periosteal thickening and destruction of the metacarpals and phalanges was noted in an eight-month-old infant by Danford and his associates. Diggs, Pulliam, and King reported periosteal elevation in the roentgenograms of three children with sickle-cell anaemia; in other patients with advanced osteosclerotic lesions, they noted irregularities in the outer margin of the cortex and periosteal new-bone formation. Grinnan found that the long bones showed a peculiar type of striation, more marked near the ends of the shafts. The upper third of the humeral shaft may show widening with thinning of the cortex and elevation of the periosteum. In the bones of the forearm widening of the shaft was observed, with thinning of the cortex in the distal end. A peculiar reticular structure was seen in the metacarpals.

The tibia and fibula have been considered the long bones most likely to show abnormality. A small series by Diggs, Pulliam, and King suggests that there is normal appearance of ossification centers, but often a delay in epiphyseal closure. Whereas in the long bones the trabecular pattern is normally of uniform size and density, in sickle-cell anaemia the pattern is disorderly; the trabeculae are found in peculiar curls, following no particular lines of stress. In the long bones, cortical thickening is usually most marked at the mid-portion of the shaft, and there may be thinning of the cortex at the bone end. Often the earliest changes visible on the roentgenograms are splotchy or diffuse areas of osteosclerosis with diminution of contrast between the cortex and the medullary cavity. The abnormal striations found in the medullary cavity follow an irregular pattern, which gradually produces sclerotic bone within the area normally occupied by bone marrow. This process tends toward complete obliteration of the marrow, but rarely has it been noted to advance to this point. The periosteum is not usually assumed to play an active role in these changes. Some workers have felt that there is a diminution in long-bone length, while others report an increase. Early observers felt that the roentgenographic changes in the long bones were similar to those of erythroblastic anaemia, but it has now been definitely established that, whereas in erythroblastic anaemia there is enlargement of the medullary cavity and thinning of the cortex, in sickle-cell anaemia there is thickening of the cortex and a diminution of the medullary cavity. Also, in sickle-cell disease there is rarely any actual increase in bone width.

In reporting the most complete studies, Diggs, Pulliam, and King stated: "Two factors appear to be working in opposite directions, one the hyperplastic marrow tending to increase its volume at the expense of bone and the other the sclerosing factors tending to replace the marrow and to substitute in its place osteoid tissue or new bone."

Correlation of the changes reported shows that children only infrequently have demonstrable roentgenographic changes in the long bones, but more often show changes in the skull. The non-specific changes of osteoporosis, bone widening, and cortex narrowing are found in young patients. In the adult, although the roentgenograms may be entirely negative, the changes, when present, reflect long-standing marrow hyperplasia and infarction which produce osteosclerosis with new-bone formation, thickening of the cortex, and impingement on the medullary cavity. The degree of the changes can be roughly correlated with the duration and the severity of the disease. This disease cannot

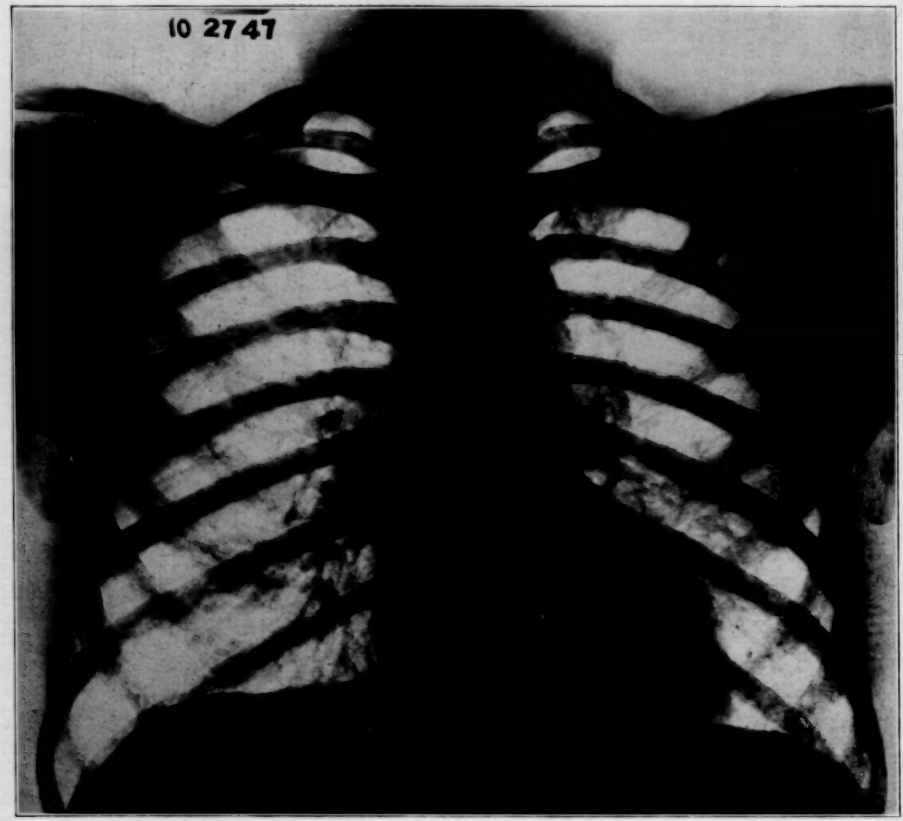

FIG. 1

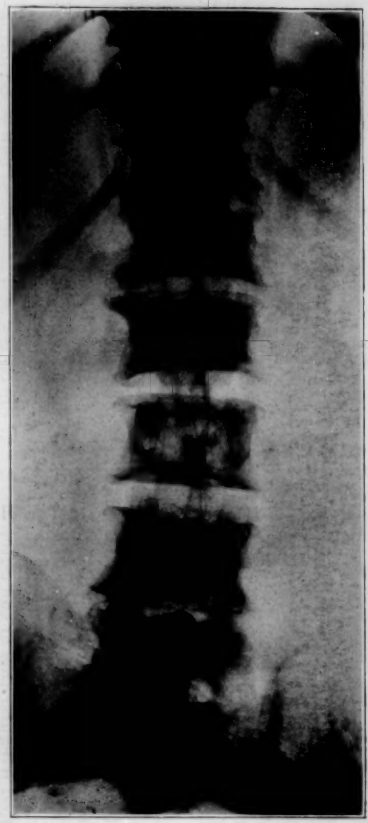

FIG. 2

Fig. 1: Roentgenogram of chest, showing increased density of the bones of the thorax and peculiar reticular striations of the ribs.
Fig. 2: The vertebrae are mildly osteoporotic with some tendency to "fish-vertebrae" appearance, and have an unusual reticular formation of trabeculae.

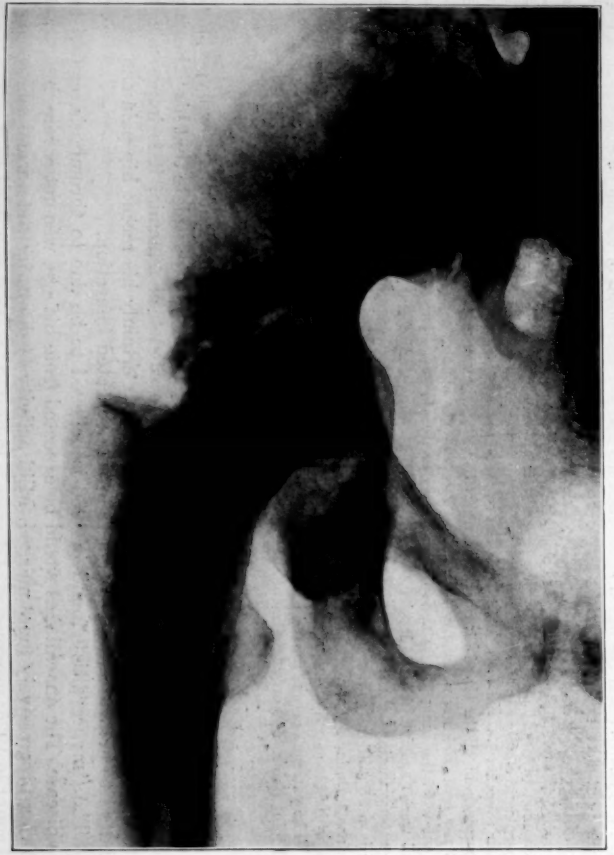

FIG. 3

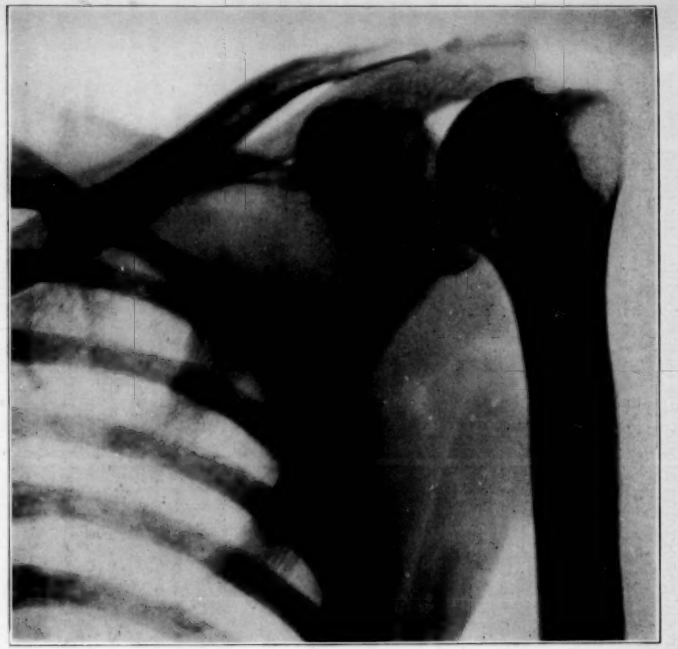

FIG. 4

Fig. 3: Typical extreme bone changes of sickle-cell anaemia. Note the osteosclerosis, diffuse and localized splotchy areas of radiolucency, inward thickening of femoral cortex with narrowing of medullary cavity, confused trabecular pattern, upward migration of acetabular cavity, and deforming arthritis. Aseptic necrosis alone does not produce all of these changes.

Fig. 4: Note the peculiar striations of the ribs, thinning of the upper cortex of the humerus, diffuse and localized areas of radiolucency, and confused trabecular pattern, which does not follow the lines of stress.

be diagnosed from the roentgenograms alone, for suspected lesions often are not verified by other laboratory studies.

CASE REPORT

F. D., a negro male, fifty-five years old, was admitted in October 1947 by transfer from another institution, where a diagnosis of metastatic bone lesions had been made.

The first admission for which records are available was in April 1935 for "heart disease". At that time the patient complained of many joint pains and of shortness of breath. The only positive finding was chronic hypertrophic tonsillitis, for which a tonsillectomy was performed. An electrocardiogram, chest roentgenogram, urinalysis, and Wassermann reaction were negative. The red-blood-cell count was 4,650,000, hemoglobin 80 per cent., and white-blood-cell count 9,500. The patient re-entered the hospital in January 1936 with a diagnosis of "cardiorenal insufficiency", but physical examination was essentially negative. The red-blood-cell count was 3,800,000, hemoglobin 70 per cent., and white-blood-cell count 8,900. Urinalysis was negative. The electrocardiogram showed left-axis deviation. A chest roentgenogram was reported as showing coarse mottling of both bases, probably due to bronchiectasis. The diagnosis at the time of discharge was chronic myocarditis.

In 1946, ulcerations developed on the anteromedial aspect of the lower portion of his right leg. He had no symptoms referable to his "myocarditis", but complained of pain in his right hip of thirty years' duration, most severe upon arising in the morning. Physical examination revealed moderate nerve deafness in the right ear, a soft blowing apical systolic murmur, tenderness over the right hip, and punched-out ulcerations over the lower third of the right leg. Roentgenograms of the pelvis, femoral heads and necks, thoracic spine, and humeral heads suggested metastatic carcinoma from the prostate. On the chest film, which was otherwise essentially negative, the posterior aspect of the ribs showed a homogeneous area of increased density.

Laboratory studies were reported as follows: blood sugar 64 milligrams per 100 cubic centimeters; urinalysis negative; red-blood-cell count 2,940,000 to 4,100,000; white-blood-cell count 13,000 to 15,000; bleeding time one and one-half minutes; coagulation time three minutes.

The patient had been a farmer and a railroad worker. Both his parents had died at middle age of unknown causes. Seven siblings were living and well. The patient was the father of one stillborn infant, but had no living children.

On admission to this Hospital, physical examination revealed a marked limp; there was almost no movement of the right hip and marked limitation of the left hip. The right thigh was two inches less in circumference than the left. The right lower extremity was three-quarters of an inch shorter than the left. There was tenderness in the region of the right hip and any movement of the hip produced pain. Several punched-out ulcerations were present on the lower medial aspect of the right leg. Roentgenographic examination of the chest was essentially negative, except for a definite increase in the density of all bones of the thorax. It was felt that the changes in the roentgenograms of the pelvis were not compatible with metastatic carcinoma, but no definite roentgenographic opinion was offered. The possibility was suggested that the hyperplastic changes in the bone marrow might be compatible with those seen in late sickle-cell anaemia. A smear revealed 100 per cent. sickling in the twenty-four-hour specimen. A sternal biopsy disclosed marked hyperplasia of all the blood-forming elements with a slightly greater increase in the erythrocytic series, and 100 per cent. sickling in twenty-four hours. Films of the shoulders, hands, and feet showed findings consistent with the hyperplastic type of bone-marrow dysplasia seen in sickle-cell anaemia, but films of the skull were negative. A gall-bladder series revealed non-function of the gall bladder, and gall stones. Other laboratory findings were: inorganic phosphorus 4.3 milligrams, calcium 10.4 milligrams, and non-protein nitrogen 35 milligrams per 100 cubic centimeters; alkaline phosphatase 2.9 Bodansky units and acid phosphatase 1 Bodansky unit; glucose 132 milligrams and uric acid 4.6 milligrams per 100 cubic centimeters. The white-blood-cell count varied between 8,000 and 18,000.

The patient's course during his stay in the Hospital was uneventful, except for persistent bouts of fever and joint pains. The only treatment recommended was blood transfusions which were purely palliative.

COMMENT

The essential changes of widespread thrombosis, infarction, and marrow hyperplasia account for the symptoms of the patient. Although one might postulate that his "rheumatism" thirty years previously had been due to sickle-cell anaemia, it is impossible to date the onset of this chronic and mild disease. Certainly his recent hip pain can be attributed to arthritic degeneration following repeated infarction.

The "myocarditis" found in 1936 is believed to be due to thrombosis, caused by this disease. The anaemia, as would be expected from his age, was not severe, but it was growing progressively more marked. Mild activity is shown by the normal white-blood-cell count in 1936; progression of disease is indicated by the recent persistent leukocytosis.

Also in favor of a late and mild disease is the absence of splenomegaly, the advanced age, the late onset of leg ulcers, the normal kidney status, and the normal blood-chemistry determinations. The icterus index was only 11, suggesting but mild hemolysis. Gall stones were anticipated, for they are common in this disease, although uncommon in the negro race. It is quite possible that the changes observed in the chest film in 1936 were due to multiple small infarcts rather than to bronchiectasis.

The bizarre roentgenograms (Figs. 1 to 4) obviously represent a far-advanced, long-standing process, as indicated by the marked sclerosis and degenerative arthritis. From a roentgenographic standpoint, syphilis, tuberculosis, Perthes' disease, osteomyelitis, metastatic carcinoma, Paget's disease, caisson disease, and sickle-cell anaemia were all considered in the differential diagnosis. Unlike some patients with this disease, this man escaped surgery for a mistaken diagnosis.

CONCLUSIONS

1. Sickle-cell anaemia may be suspected from roentgenographic findings, but cannot be definitely diagnosed from such evidence alone.

2. In older patients the symptoms of bone and joint disease, rather than the anaemia, may bring the patient to the attention of the physician.

3. The bone changes are due to a combination of bone-marrow hyperplasia and repeated infarction.

NOTE: The writer wishes to acknowledge the assistance of Robert Kelly, M.D., and Paul Reith, M.D., in the preparation of this paper.

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NON-TUBERCULOUS THORACIC KYPHOSIS WITH PARAPLEGIA

A Case Report

BY COMMANDER WILLIAM H. GULLEDGE, *Medical Corps, United States Navy*
AND COLONEL ERNEST A. BRAV, *Medical Corps, United States Army*

From the Orthopaedic Section, Tripler General Hospital

The infrequency of case reports of scoliosis and kyphosis with paraplegia, excluding spinal deformities due to tuberculosis, indicates the rarity of the condition. Forty-one cases of this type have been reported. The following case is of interest because the kyphotic element was the predominant deformity, whereas in the great majority of cases previously reported the scoliotic element was the cause of the paraplegia.

An Army private, twenty-one years old, was admitted on September 12, 1949, with the chief complaint of weakness in both legs. About five weeks prior to admission he had been unable to do an about-face because of weakness of the right leg. This disability progressed and his legs were stiff and tender, particularly in the morning on arising. When it became impossible for him to walk without support, he was admitted to the

Hospital. The past history revealed that he had had a marked round-back deformity since the age of five. In spite of this he lived a normal life, was athletic at school, and had enlisted in the Army fourteen months prior to admission. There had been no recent trauma and no apparent increase in the deformity. There was no personal or familial history of tuberculosis.

Physical examination revealed a well developed young man with marked thoracic kyphosis and a pigeon-breast deformity (Fig. 1). The head and upper extremities were normal. Beginning at the tenth thoracic level, there was diminution of sensation to pinprick and light touch. Below this point there was progressive sensory loss, most marked over the toes. There was marked generalized muscle weakness of the lower extremities, particularly on the right side. Position sense was absent and vibratory sense was diminished. The patellar and Achilles reflexes were hyperactive and there was bilateral sustained ankle clonus. The Babinski sign was present bilaterally. The patient walked with a spastic gait and required the use of a cane.

FIG. 1

Photograph of patient showing severe thoracic kyphosis and moderate pigeon-breast deformity.

Roentgenograms showed the severe thoracic kyphosis with anterior wedging of the vertebral bodies. The most marked deformity was of the bodies of the seventh to the tenth thoracic vertebrae, and there was considerable irregularity of the upper and lower vertebral margins. Minimal scoliosis was present. The roentgenographic appearance was thought to be the result of an old healed vertebral osteochondrosis (Figs. 2-A and 2-B). Roentgenograms of the chest revealed no evidence of pulmonary disease.

A spinal puncture was performed; the fluid manometric pressure was normal. The protein content was 32 milligrams per 100 cubic centimeters of spinal fluid. The patient was first treated by bed rest in slight hyperextension, but the symptoms increased in severity. On October 24, 1949, a myelogram was made, 3 cubic centimeters of pantopaque solution being used. The solution flowed freely until it reached the level of the tenth thoracic vertebra, where it split into two columns, which continued to flow slowly past the area of maximum kyphosis.

On November 3, a laminectomy from the seventh to the tenth thoracic vertebrae was carried out *. The articular facets were not disturbed. There was a normal amount of epidural fat, and the space between the dura and undersurfaces of the laminae appeared to be herniated. The dura was opened in the mid-line through the full extent of the exposure. It was tightly compressed against the posterior portion of the cord so that, as it was opened, it retracted laterally and the cord herniated through the gap. The dura was split until it no longer tended to compress the cord. Three horizontal incisions were then made in the dura on each side of the vertical split. The dura was obviously under considerable tension, and the incisions permitted it to retract laterally so that its edges were barely visible. When this procedure had been completed, the cord presented a normal appearance and had apparently been relieved of the posterior pressure. A rectangular piece of polyethylene film was laid over the exposed cord and held in position by sutures to the edges of the dura. The muscles and skin of the back were then closed in layers with silk.

The postoperative course was uneventful. On the first postoperative day there was marked subjective improvement. The patient stated: "My legs now feel as if they belong to me". His spasticity had definitely diminished. The clonus on the left was present but unsustained; that on the right was less marked. An indwelling catheter was required for four days, but after that time there was no bladder or bowel difficulty. Two weeks after the operation the sensory level had disappeared and there was diminished sensation to pinprick only in the saddle area on the right. There was no clonus on the left, and clonus was less easily obtained on the right side. Position sense was still absent. There was considerable increase in muscle power of the lower extremities.

The patient was fitted with a Taylor back brace and was allowed up on the fourteenth postoperative day. A week later his strength had returned sufficiently for him to start walking with assistance. Weight-bearing was soon accomplished with the aid of a cane. Two months after operation some spasticity and muscle weakness still remained, but progressive improvement was evident.

* By John H. Lowrey, the neurosurgical consultant.

FIG. 2-B

FIG. 2-A

Fig. 2-A: Anteroposterior roentgenogram showing minimal scoliosis. The outlines of the pedicles have been marked with dots.
Fig. 2-B: Lateral view showing severe kyphosis with wedging of the mid-thoracic vertebrae, especially between the seventh and the tenth. There is also marked irregularity of the superior and inferior margins of the involved vertebral bodies and some narrowing of the discs.

Nine months after operation there was still some weakness of the lower extremities, but the patient complained of tiredness and shaking of the legs only after he had been walking without support for about a mile. He was able to engage in ordinary detail duties in his barracks, and carrying duffel bags up a flight of stairs presented no difficulty. Hyperactive reflexes were still present bilaterally, but the only area of remaining hypoaesthesia was on the dorsum of the right foot. The patient felt that he was able to "do as much as anybody here", but his residual weakness and spasticity were the basis for a discharge for disability. However, the prognosis for resumption of ordinary civilian activity appeared favorable.

COMMENT

A review of the literature on this subject was recently made by McKenzie and Dewar, who included five cases under their own care. Among the forty-one cases reported, twenty-four were treated by laminectomy; fifteen patients made a satisfactory recovery. In two of these cases the dura was not opened becasue the cause of compression was extradural,—due in one case to a congenital constricting band and in the other to a bony outgrowth. In the remaining thirteen cases the dura was opened and was not sutured. The benefit gained from operation was clearly due to release of tension on the spinal cord by the tightly stretched dura. This finding was similar to that noted in the authors' patient. The use of the polyethylene film over the exposed cord at the time of the wound closure has not been mentioned in the cases of this type which have previously been reported.

Of the twenty-four cases treated by laminectomy, there were three deaths. Two patients died within a few hours of the operation and one died several weeks later, as a result of general debility and a spreading cellulitis secondary to decubiti. In six cases the result of the operation was poor; one later proved to be a case of syringomyelia. Two of these patients had had neurological symptoms of more than two years' duration, and in both of them the cord was pale and flattened at the time of operation. One patient had symptoms of only three months' duration, but the cord was also pale and badly constricted. Two cases were complicated by postoperative hematomata which required evacuation.

In the entire series reported, fourteen patients were treated by conservative measures alone. In three cases there is no adequate record of treatment or results. By the use of traction, back supports, and in one case a spine fusion, improvement was noted in eleven of the fourteen patients; in at least five of these the results were apparently satisfactory and persistent. In one case there was temporary arrest in the progress of the paralysis and in two there was no change.

Ten of the patients operated upon had been treated earlier by conservative means without success. It would seem inadvisable to continue non-operative treatment for long periods, because of the possibility of producing irreversible cord damage. Since laminectomy and decompression is not a dangerous procedure in skilled hands, it is the logical approach when a brief trial of conservative treatment appears to offer little chance for improvement.

The remarkable features of the authors' case are the presence of severe thoracic kyphosis rather than the scoliosis which is reported in most patients, and the late development of progressive neurological changes after a long period of years without the occurrence of either superimposed trauma or any obvious exaggeration of the bone deformity. The case is an unusual one in our experience, and presented an encouraging response to prompt operative intervention.

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ARTHRODESIS OF THE HIP FOR INSTABILITY AND PAIN IN POLIOMYELITIS *

BY HALFORD HALLOCK, M.D., NEW YORK, N. Y.

Since February 1929, at the New York Orthopaedic Hospital, arthrodesis of the hip has been performed upon thirteen patients for painful paralytic dislocation or severe limp from extensive hip-muscle paralysis. Fusion was done because, in the past, open reduction, shelf stabilization, and muscle transplantations had not been wholly satisfactory in solving this problem. In the beginning, the procedure was employed only in those instances in which there was a painful subluxation or dislocation; but, because in these cases such marked improvement in gait occurred, it was used later in several individuals with a severe hip lurch without dislocation. The first six of these patients were reported in 1942[1].

The number of patients is small, because dislocation is not a common complication in residual poliomyelitis, and probably because the possibility of arthrodesis is not often thought of in observing patients with a severe hip limp due to muscle paralysis alone.

At first it was believed that arthrodesis was contra-indicated in the presence of marked weakness or paralysis of the quadriceps. It has been found, however, that such knees are stable if the ligaments are sound, if there is no significant flexion deformity of the joint, and if the foot and ankle are strong or have been stabilized by subtalar (triple) or pantalar arthrodesis in a position of moderate equinus.

PREOPERATIVE DATA

The ages of the patients at operation averaged nineteen years, varying from thirteen to thirty years. There were three males and ten females. The average time of arthrodesis after the onset of the poliomyelitis was eighteen years, and it varied from eleven to thirty years. The patient who was thirty years old when operated upon had contracted the disease only a few months after birth.

Six of the patients complained of pain while only two complained of fatigue in the hip. In all of them, a dislocation or subluxation was present. One other had a dislocation, but he denied discomfort. Four patients were operated upon because of a severe paralytic hip limp, but without loss of structural joint stability.

In general, paralysis of the hip muscles was extensive and marked. One patient had failed to obtain a satisfactory result after an open reduction and shelf stabilization, followed by traumatic and circulatory complications which resulted in persistent dislocation and pain. The most severe disability was in a young man of twenty who walked with great difficulty, with both hands on a cane, because of a marked instability of the hip and a painful slipping of the joint.

In all of the patients, the knee joint on the affected side had satisfactory ligamentous stability. Quadriceps power, however, was normal or good in only five patients, zero in one, poor plus in one, fair in four, fair plus in two. Five patients complained of knee weakness; in four of these, a flexion deformity of the knee was present, amounting to 5 degrees in one patient and 10 degrees in three patients, all with quadriceps weakness rated as 0, poor plus, fair, and fair plus, respectively. The deformity was corrected by wedging plaster casts in three and by a supracondylar osteotomy in one. Except for the possible effect of the hip dislocation, the knee weakness in the fifth patient was otherwise unexplained, as the quadriceps was good and there was no deformity of the articulation.

The ankles and feet on the affected side were stable in two patients. In all the others stabilization was, or had been, achieved,—by subtalar arthrodesis (in three patients),

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 14, 1950.

TABLE I

LIMP BEFORE AND AFTER HIP FUSION

Limp	Before Operation	After Operation
Slight	0	6
Moderate	0	3
Marked	6	0
Severe	5	1

by astragalectomy (in one patient) and by pantalar arthrodesis (in seven patients). In one patient with a poor quadriceps and a flail foot, only a subtalar arthrodesis was performed. She still has knee weakness in which the instability of the ankle is definitely a contributory factor.

TABLE II

SYMPTOMS BEFORE AND AFTER OPERATION

Symptoms	Before Operation	After Operation
Pain	6	0
Fatigue	2	0

The quadratus lumborum muscles were strong in all the patients except one.

The opposite leg was functional in all the patients, although in one the hip was flail, the knee fused, and the foot stable following pantalar arthrodesis. This patient also had bilateral weakness of the quadratus lumborum muscles and used crutches for walking. She had severe pain in the right hip, which was subluxated. Another patient had a marked ligamentous relaxation of the knee with genu valgum and genu recurvatum, but, fortunately, the muscles were strong. Three others had had subtalar arthrodesis, and two, pantalar arthrodesis.

Two patients used canes and one used crutches.

TYPE OF ARTHRODESIS

Except in one patient, in whom the head and neck of the femur had been destroyed as a result of traumatic and circulatory complications following a shelf stabilization, all had arthrodesis of the intra-articular type with the removal of the cartilage from the femoral head and the acetabulum. In one, this excision was only partial. In the one for whom this type of arthrodesis was not suitable, fusion was done by a graft from the trochanter, after replacement of the end of the shaft in the acetabulum. Trochanteric grafts, after the manner of Hibbs, also were employed in seven patients, and a graft from the ilium was used in one patient. In two patients, who were operated upon only recently, transarticular fixation was effected, after intra-articular removal of the cartilage, by three square arthrodesis nails, two introduced intrapelvically and one introduced from above downward or from the head into the ilium. An iliac graft was employed or chips were used in addition. In one patient, open reduction was performed with an intra-articular removal of the cartilage, but without grafts or fixation other than a plaster spica.

In one patient with a dislocation, it was necessary to fuse the femoral head to the ilium at the level of the false acetabulum. In another, preoperative Kirschner-wire traction was successful in bringing the head down to a position opposite the socket.

There were no postoperative complications and no deaths. In general, walking in a plaster spica was permitted three months after operation, and plaster fixation was termi-

nated from four to eight months after surgery. Two patients are still in plaster casts as they were operated upon only recently.

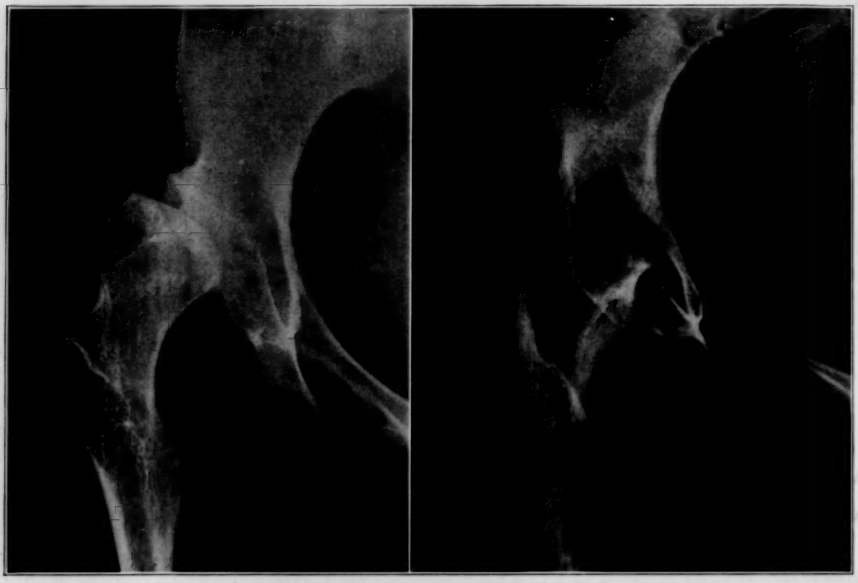

FIG. 1

E. D. Before and thirteen years after operation. The knee is stable, although the quadriceps is useless.

FIG. 2

M. G. Before and seven years after fusion.

RESULTS

Eleven of the thirteen patients have been examined from one to twenty years after operation. The average follow-up time is nine and five-tenths years. All have fused hips, by clinical and roentgenographic standards, and all are free from pain. Two patients had re-fusion operations as each failed to obtain an arthrodesis by the primary procedure. All,

FIG. 3

M. G. Before and eight years after operation.

FIG. 4

H. M. Before and fourteen years after arthrodesis.

TABLE III

FINAL POSITION OF FUSION AND SHORTENING

Case	Flexion (*Degrees*)	Abduction (*Degrees*)	Adduction (*Degrees*)	Internal Rotation (*Degrees*)	External Rotation (*Degrees*)	Shortening (*Inches*)
1	40	15				2.5
2	35	10			5	2
3	45					2
4	25	5			5	1
5	40		5			0
6	40	10		5		2
7	"Good position"					1
8	35					2.5
9	25	15				No note
10	30		20			1.25 (functional)
11	45	25				3
Average	36	13				1.72

except one, have a slight or moderate hip limp, instead of a marked or severe one as preoperatively. The exception is the patient with extensive bilateral involvement who, in the opposite limb, had a flail hip, fused knee, pantalar arthrodesis, and weak quadratus lumborum muscles. Although she has been relieved of the severe pain in her right hip, due to the subluxation, she still limps badly, has a weak right knee, and uses crutches. In addition, stair-climbing has been made impossible for her by the combination of right-hip and left-knee arthrodeses in the presence of weak quadratus lumborum muscles. The improvement in gait and symptoms in these patients is illustrated in Tables I and II.

Only two patients postoperatively have unstable knees. Both joints were weak before operation. In one there is a 10-degree flexion deformity, a poor quadriceps muscle, and a flail ankle. The patient uses a single crutch. It is believed from past experience that this knee can be stabilized by supracondylar osteotomy for correction of the flexion deformity and arthrodesis of the ankle in equi us of 10 or 15 degrees. In the other, the patient with extensive bilateral paralysis, the quadriceps is only fair and the pantalar fusion is complete, but not in a position of equinus.

The optimum position of fusion is considered to be flexion of 35 degrees, and neutral lateral and rotatory position, except in women or where considerable shortening is present, when 10 or 15 degrees of abduction are advisable for biological reasons and to compensate in some measure for the inequality of leg length. Table III gives the final positions of fusion and the amounts of shortening. Abduction is probably excessive in one (25 degrees), although it is fairly well handled because of three inches of shortening. Another patient has too much adduction (20 degrees). In one patient, a subtrochanteric osteotomy was performed five years after fusion to correct excessive flexion (60 degrees).

COMMENT

The results in this series of patients have been most gratifying. The arthrodesis has relieved pain, achieved stability, and has reduced the limp far more than would have been possible by shelf stabilization, which in no way could have compensated for that portion of the instability due to the muscle paralysis. Adequate ligamentous stability of the knee is a prerequisite, as increased strain is imposed upon this joint which, in these patients,

usually does not possess normal muscle strength. While functional quadriceps power is a distinct advantage, it does not seem to be a necessity, as one patient without any power has a stable knee thirteen years after operation. It is obvious, however, that in instances of quadriceps insufficiency, there must be no significant flexion deformity of the knee, and the foot and ankle must be stable or made so by subtalar (triple) or pantalar arthrodesis in a position of 10 or 15 degrees of equinus.

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DISCUSSION

DR. ROBERT W. JOHNSON, BALTIMORE, MARYLAND: It is always a pleasure to see patients at a big medical meeting. So much of our work is now presented by movies, discussion, roentgenograms, and statistics that sometimes I feel that we almost forget the individuality of the patients with whom we are dealing. Dr. Hallock has presented these excellent patients and, if we had not had such unfortunate weather, there would have been twice the number of patients. They show most graphically, I think, in their expression, in their ability to move around, and in their evident comfort, the end results that can be expected from this operation when it is wisely used. My own experience with it is necessarily limited, as I think everyone's will be. There are only a few cases which fall into this category, since it takes a very special set of circumstances to make such an operation advisable. Since Dr. Hallock has brought out these factors very well, I can but add my own satisfactory experience in doing at least one case with absent quadriceps on the same side. There has been no difficulty from the knee giving way since the hip was stabilized; whereas, before the operation there had had to be constant pressure on the knee whenever this girl moved about. The radius of activity has been enormously extended and I think that these factors—the absence of pain, the increased endurance, and the extension of what these patients can do—are the rewards of well selected arthrodesis in the manner that Dr. Hallock has described.

I have no points of warning or suggestion to add, because I think he has not only selected his cases well, but has also demonstrated clearly the limits within which the procedure is indicated and, to a certain extent, the contra-indications. The greatest contra-indication, in my experience, has been a flail condition of the foot, which should be dealt with first. I believe in beginning with the foot and working up to the hip.

DR. LEO MAYER, NEW YORK, N. Y.: For all of us who are interested in the treatment of infantile paralysis, this has been a valuable paper. It has shown us what had to be done for patients who otherwise would have been forced to walk with a crutch or a brace or even two crutches. I do not believe there is much doubt about the efficiency of the operation in cases where there is a dislocation or a subluxation, particularly when this condition is painful. I am particularly interested in another phase of the indications for the operation,—namely, when the femur is within the socket. In cases of very extensive paralysis, or what might be called the "dangle hip", the gait is a very marked limp, and patients are compelled for that reason to use crutches. A brace under those conditions does not help the patient much. For that particular type of condition, I performed the arthrodesis in four cases, always with a little misgiving because it is a rather extensive operation. I want to call your attention to one possible disadvantage of the operation which is the difficulty of sitting, but you noticed that the two patients whom Dr. Hallock has shown today are sitting quite comfortably in the front seats. They seem to have no trouble with the spine, and I do not believe they have any pain. If they do, they certainly show no indication of it. None of my patients had any pain as a result of the fusion operation; however, it is true that they were all younger individuals,—no patient over the age of eighteen. They all walked fairly well, although a slight limp persisted.

The effect in one case was really quite remarkable. A girl, who until that time had barely been able to walk with the aid of two crutches, following the operation entered high school, was graduated, and, at the present time, is holding a good job as a secretary. I am sure the operation was a great benefit to her.

I am much indebted to Dr. Hallock for this presentation, since it stimulates us to go ahead and use this operation a little more frequently than we have in the past. Fifteen operations over a long period of time is a very small number for a hospital the size of New York Orthopaedic. At the Hospital for Joint Diseases we have had also only a small group of these patients. I think the indications of the operation should be somewhat enlarged, always however, with due regard to the important condition of the abdominal muscles. Do not do it if the abdominal muscles are paralyzed. If you do, you will be disappointed in the results.

DR. HALLOCK (closing): I would like to thank the discussors very much for their kind words.

One of the two patients shown here this morning recently has begun to have some pain in his low back and cervical spine. The roentgenograms show what we believe to be some mechanical instability in the lumbosacral joint and a little osteo-arthritis in the cervical spine. Except for this patient, as far as I know, our patients have not been troubled with low-back pain. In this particular patient, you will remember, the hip was fused in flexion of 45 degrees and in abduction of 15 degrees, which does put a good deal of strain on his lumbar spine; thus, it is possible that the position of his hip is a factor in the beginning discomfort in his low-back region.

INFLUENCE OF PROGRESSIVE-RESISTANCE EXERCISES ON KNEE FUNCTION FOLLOWING FEMORAL FRACTURES *

BY CAPTAIN THOMAS L. DELORME, *Medical Corps, Army of the United States*
LIEUTENANT COLONEL FRANCIS E. WEST, *Medical Corps, Army of the United States*
AND WILLIAM J. SHRIBER, M.D., BOSTON, MASSACHUSETTS

From the Orthopaedic Section, Gardiner General Hospital, Chicago, Illinois

INTRODUCTION

The most frequent and severe complication of a femoral fracture treated by conventional methods is the impairment of knee function. Normal knee function, following simple, uncomplicated fractures, can by no means always be obtained; and, with an increasing number of complications, the chances of recovering normal function steadily decline. Although a well controlled and planned regimen of physical therapy and rehabilitation will increase the functional capacity of the knee joint following this type of injury, there is no doubt that such a program still falls short of restoring the maximum function of which the injured joint is capable. The physiological responses to progressive-resistance exercises justify their use in treatment of this condition, and the present study was undertaken to see whether this type of exercise therapy would improve knee function beyond that obtained by the usual physical therapeutic regimen. The large number of femoral fractures encountered in World War II provided an excellent opportunity to study the response of the knee to this type of exercise therapy.

PROCEDURE

All of the patients included in this study were hospitalized at Gardiner General Hospital, Army general hospital of the Sixth Service Command, Chicago, Illinois, and were treated in the Orthopaedic Section. Practically all patients with fractured femora were in the same phase of recovery when admitted, usually one or two months following injury. Initial treatment had consisted of treatment for shock, débridement, immobilization, and in some cases secondary closure after a week or more. Patients were then placed in double spica casts for transportation to the Zone of Interior. Immediately upon arrival of the patients at Gardiner General Hospital, their casts were removed and roentgenograms were made. Subsequent treatment was initiated as soon as preliminary evaluations of disability were completed.

The data presented here were collected by members of the Orthopaedic Section, using the same technique of evaluation,—goniometer, strength tests, *et cetera*. Indeed, approximately 90 per cent. of the measurement was made by the same two individuals.

The 199 fractures in this study represent 199 patients. Patients with bilateral fractures were not included, because the results of treatment in one extremity inadvertently influenced the results in the other. All patients were in the age group of eighteen to thirty-five, and all injuries were sustained while on active duty.

Symptomatic evaluations and goniometric measurements of knee extension and flexion were made on all patients immediately before discharge. Therefore, the group not given exercises serves as a control for the group which received progressive-resistance-exercises. In addition, before-and-after measurements of thigh circumference and strength were obtained for the group given exercises. Complete extension was recorded as 180 degrees and full flexion as 45 degrees.

For one reason or another, some patients were placed on the progressive-resistance-exercise program and some were not. Usually patients with more severely impaired knee function were selected for this additional exercise therapy. As this type of treatment

* Publication of this study was made possible by the Pope Foundation, Inc., Kankakee, Illinois.

initially was not part of the standard physical-therapy regimen, it was not compulsory; and many patients instead went on work furloughs or to a convalescent center, where they received standard physical therapy until they returned to Gardiner General Hospital for discharge. Regardless of the type of treatment, all end-result data considered here were obtained immediately before discharge from Gardiner General Hospital. Throughout the remainder of the paper the patients who received progressive-resistance exercises will be referred to as the "exercised group", and those who did not as the "unexercised group".

The unexercised patients received routine physical therapy until their gains reached a certain level or until they were ready for a more strenuous rehabilitation program on which they remained until they were discharged. The treated patients (exercised group) had exactly the same care, with the exception that they received a trial of progressive-resistance exercises. The progressive-resistance exercises were in addition to standard physical therapy and rehabilitation, and did not supplant any other form of therapy.

During the absolute immobilization period all patients, unless it was otherwise contraindicated, received luminous heat, massage, and supervised daily quadriceps drill until sufficient union had occurred to permit knee motion. Patients were then placed in a Thomas splint with a Pearson attachment, which enabled knee flexion and extension exercises. These exercises were continued until sufficient union had occurred to allow ambulation, the nature of which depended on the site of fracture, degree of union, and urgency for mobilization. The usual procedure was to have patients with mid-shaft, lower-shaft, and condylar fractures become ambulatory in a toe-to-groin, ischial weight-bearing brace. Patients with higher femoral fractures became ambulatory on crutches without a brace, and a few were able to bear full weight immediately after becoming ambulatory. When beginning ambulation, the patient received treatment in the physical-therapy department, which usually consisted of whirlpool baths, massage, and passive and active knee extension and flexion exercises. Gentle passive manipulation of the knee into flexion was frequently administered. As improvement occurred and union became more solid, treatment became more vigorous and rehabilitation activities advanced. One might well have the impression that, on discharge from a general hospital, insufficient time had elapsed since removal from traction to permit an appreciable return of the knee-joint motion, but this was hardly ever so. Except in certain instances, these patients were not discharged from Gardiner General Hospital until union was sound and rehabilitation was advanced. Many patients were transferred to a convalescent center to continue routine physical therapy while waiting for union to progress, but these were routinely returned to Gardiner General Hospital for evaluation of disability before final disposition was made.

Progressive-resistance exercises were cautiously initiated as soon as the patient became ambulatory and began treatment in the physical-therapy department. In no instance was there a refracture or other injury caused by the heavy exercises, even though at their initiation many of the fractures were not shown by roentgenogram to be absolutely fused. The successful handling of so many femoral fractures without refracture is probably due to several factors: First, determination of the 10 RM * was delayed several weeks if union was not satisfactory, and the 20 or 30 RM level was used in the interim. Second, determination of the 1 RM ** was avoided in suspicious cases. Paradoxically, exercising with weights consistent with the patient's muscle power is, within limits, much safer than passive exercise and manipulation with relaxed musculature, for, with increasing muscle tension, there is an increased splinting action of the contracting muscles, which resists the bowing tendencies of the shaft. Third, if doubt existed concerning the degree of union, the technician manually applied down pressure, roughly equal to that tending to raise the thigh, either at the site of the fracture or slightly below it.

* Term referring to the greatest weight that can be correctly carried through the available range of motion for 10 repetitions (10 RM). It is expressed in pounds in this study.

** Term referring to the greatest weight that can be lifted for one repetition instead of ten. It represents the maximum volitional effort.

All strength data in this study are recorded in pounds and represent the 10 RM. The 1 RM was not employed as an index of strength as originally described [2], for it was felt that too many of the patients might have insufficient union to permit such a strenuous initial effort; however, it was employed later to stimulate maximum effort. Expressing strength in terms of a 10 RM is justifiable, since it bears a constant relationship to the 1 RM. Those patients with union so poor as to prohibit determination of a 10 RM were not included in this part of the study.

Patients of the exercised group received three basic exercises: knee extension, knee flexion, and combined knee and hip extension. The knee-extension exercise was usually performed in the sitting position; but, if relaxation of the hamstrings or stretching the rectus femoris to develop more tension was desired, it was performed in supine position. After prolonged enforced inactivity, the strength of the uninjured thigh naturally had deteriorated. Therefore, when possible, bilateral progressive-resistance exercises were given, as soon as its strength was matched by that of the injured thigh. Knee-flexion exercises were stressed, since it was felt that strong knee flexors would be helpful in gaining knee flexion and in taking advantage of the newly acquired knee flexion gained in stretching. A combined hip and knee exercise was employed to gain knee flexion and to increase extensor power. It is different from the knee-extension exercise since, in this exercise, the resistance to quadriceps contraction is greater in flexion and less in extension. All of these exercises have been illustrated and discussed in detail in a previous issue [2].

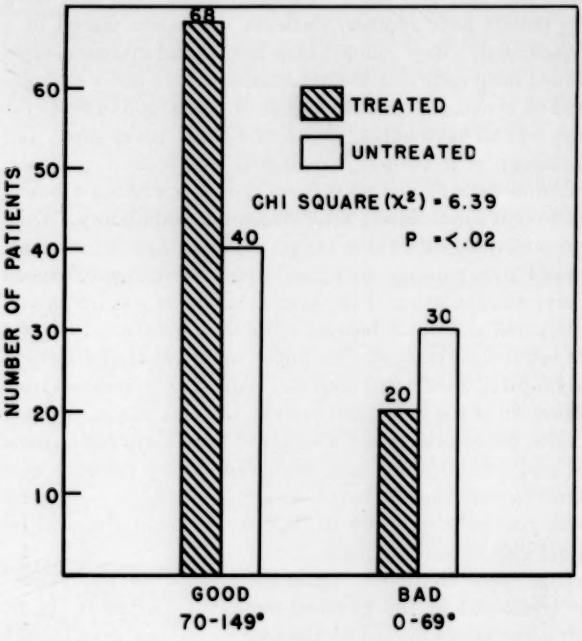

CHART I

All patients exercised once daily three to five days a week according to the principles originally described [2]. Three weeks was selected as the minimal period of progressive-resistance exercises that could be considered a fair trial, although maximum results could not be obtained in so short a period. Patients receiving progressive-resistance exercises for less than two weeks were placed in the unexercised group. Therefore, gains made in this period were credited to the unexercised group rather than to the exercised group. It is reasonable to assume also that, if all participants of the exercised group had remained on progressive-resistance exercises until maximum results were obtained, a fairer evaluation of the therapeutic effectiveness of the exercise technique would have been possible.

Wounds draining longer than one month after injury were treated as chronic draining wounds and were considered separately from those healed within this period. Injuries were classified according to type—fracture simple complete (F.S.C.) and fracture compound complete (F.C.C.)—duration of drainage period, and treatment with or without progressive-resistance exercises. Incomplete fractures were not included in the study since

they did not as a rule entail the prolonged and highly definitive treatment of the group of complete fractures.

Circumference gains are given in inches. The site of measurement (mid-thigh) was permanently marked with silver nitrate. The same technician took all circumferential measurements and reached a high degree of accuracy in obtaining readings, reproducible within one-quarter inch.

Strength values are expressed in pounds and represent the 10 RM determined as described elsewhere [1].

The 199 femoral fractures are divided into two large groups:

Group I—Shaft fractures	158
Group II—Condylar fractures	41
	199

Both groups include compound and simple fractures which were treated by different methods. They also include those with complications such as non-union or delayed union caused by chronic infection, malposition, or distraction.

Group I consists of eighty-eight exercised patients and seventy unexercised patients and the final range of motion of the exercised and unexercised groups are compared. Each of the two groups of eighty-eight and seventy contains a similar distribution of simple and complete fractures, chronic draining wounds, *et cetera*, and they are therefore comparable. A further, and probably more significant, comparison is made of exercised and unexercised patients who had similar treatment, periods of immobilization, and types of fracture.

The condylar group, Group II, consists of eighteen exercised and twenty-three unexercised, and is evaluated similarly to Group I.

In Groups I and II, two methods of evaluation were employed. In one the influence of treatment on range of motion was designated as good if there were 70 or more degrees of knee motion, and bad if there were less than 70 degrees. The reasons for selecting 70 degrees as the dividing line are: 70 degrees is about one-half of the total knee-joint motion, and, with 70 degrees or more, the functional limitations are not too severe except in certain cases. With less than 70 degrees, stair-climbing becomes difficult and when sitting it is difficult to get the feet out of the way of passers-by or to get the feet within the space allotted in a theater seat or street car.

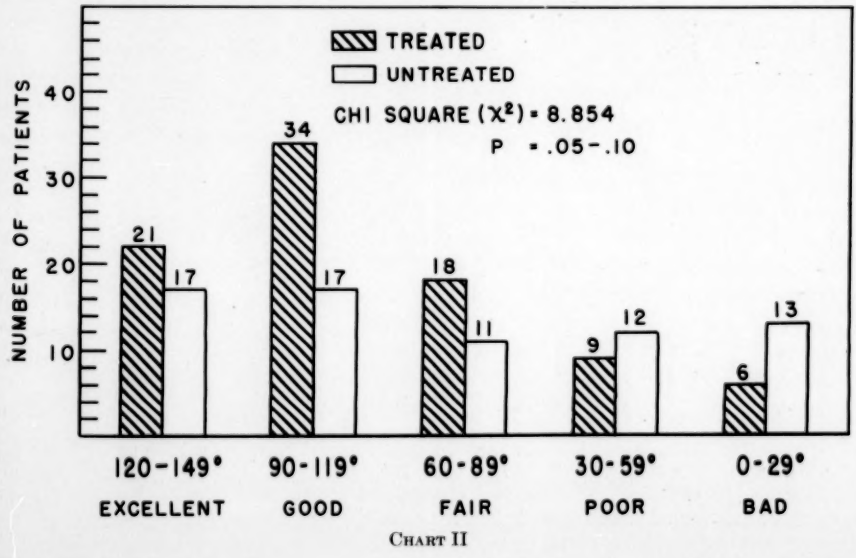

CHART II

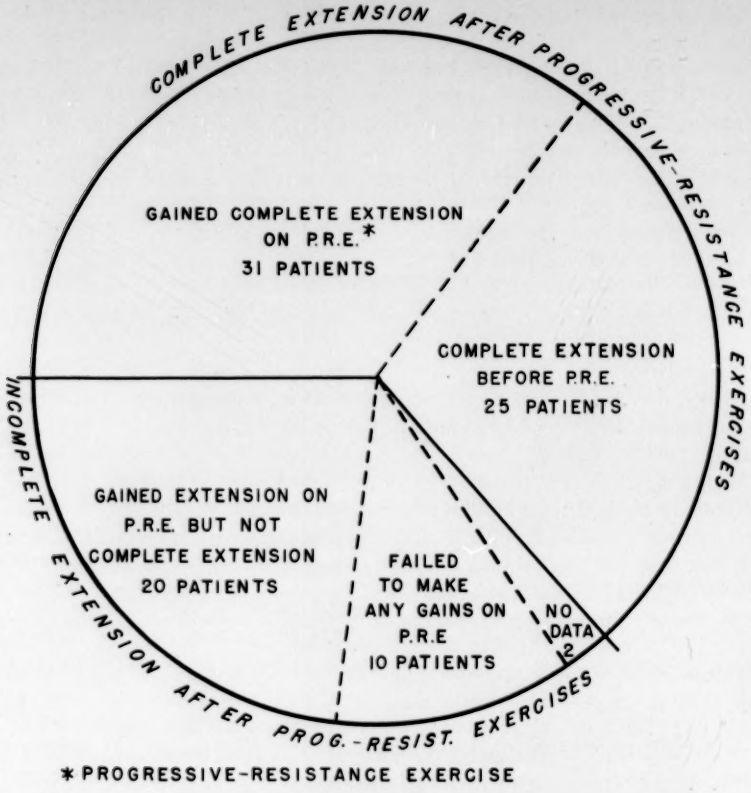
COMPLETE EXTENSION AFTER PROGRESSIVE-RESISTANCE EXERCISES
GAINED COMPLETE EXTENSION ON P.R.E.* 31 PATIENTS
COMPLETE EXTENSION BEFORE P.R.E. 25 PATIENTS
GAINED EXTENSION ON P.R.E. BUT NOT COMPLETE EXTENSION 20 PATIENTS
FAILED TO MAKE ANY GAINS ON P.R.E 10 PATIENTS
NO DATA 2
INCOMPLETE EXTENSION AFTER PROG.-RESIST. EXERCISES
*PROGRESSIVE-RESISTANCE EXERCISE

CHART III

For more detailed comparison, both groups were subdivided into five smaller groups, based on the following ranges of motion:

Failure	0 to 29 degrees
Poor	30 to 59 degrees
Fair	60 to 89 degrees
Good	90 to 119 degrees
Excellent	120 or more degrees

The purpose of this more detailed study is not only for comparison, but also to determine where progressive-resistance exercises were most effective.

The three most easily measured, important clinical effects of progressive-resistance exercises in this type of injury are on: range of motion, muscle size, and strength. These measurements were made and recorded as previously described [2]. This study deals chiefly with changes in knee motion as a result of progressive-resistance exercises. However, an evaluation of functional capacity includes a consideration, not only of motion, but also of muscle strength and bulk, as well as of subjective symptoms. An evaluation was made of the objective and subjective knee symptoms of the exercised and unexercised patients before discharge.

The symptoms evaluated were: pain, swelling, fluid, and crepitus. Although during the course of treatment the severity of the symptoms was rated on a plus basis (with + representing a minimum, and ++++ a maximum), for this study they are considered only as present or absent with no attempt made to evaluate intermediate grades.

For the entire group of 199 patients the mean period of follow-up (the number of days from injury until final evaluation and discharge) was thirteen months. The mean time of follow-up for the 106 (eighty-eight shaft and eighteen condylar fractures) exercised patients was 389 days, and for the ninety-three unexercised (seventy shaft and twenty-three condylar fractures) patients was 393 days. The mean period for both exercised and unexercised patients who were on full, unrestricted activity before final evaluation was approximately three months. Thus, the final evaluation of the disability of each was made at approximately the same phase of recovery. The data presented herein are not end-result data, but are indicative of the progress of the exercised and unexercised at approximately the same stage of recovery. Ideally, final evaluation of disability should have been deferred until both exercised and unexercised had attained maximum function. This, however, was not possible and it is felt that the data presented here, though not complete, suggest definite valuable therepeutic trends.

DATA

Joint Motion

Of the 158 shaft fractures, eighty-eight were treated with progressive-resistance exercises, and seventy were not. The many complicating factors, previously named, were evenly distributed throughout these two groups, and the initial step in evaluation of progressive-resistance exercises was a comparison of their range of motion data. Results were rated as *good* or *bad*, with the former rating given to those knees with 70 degrees or more of motion and the latter rating to those with 69 degrees or less. Sixty-eight of the eighty-eight exercised patients (77 per cent.) were rated *good;* whereas, forty of the seventy (57 per cent.) unexercised received a *good* rating. These data were treated statistically and a chi-square determination revealed a probability value of less than .02, indicating that some factor other than chance was responsible for the exercised group presenting a better result. Progressive-resistance exercises were the only difference in therapy that the two groups received; and, therefore, it is logically assumed that progressive-resistance exercises were responsible for the better result. Chart I illustrates the results of this evaluation.

	TYPE OF FRACTURE		SITE OF FRACTURE			SURGERY				TRACTION	
	SIMPLE	COMPOUND	UPPER 1/3	MID-1/3	LOW-1/3	NONE	SCREWS	PLATE	BOTH	SKIN	SKELETAL
EXERCISED	25	10	7	23	5	27	1	6	1	8	19
UNEXERCISED	16	16	8	21	3	25	0	7	0	4	21

	TOTAL IMMOBILIZATION PERIOD			ABSOLUTE FIXATION PERIOD				TIME FOLLOWED				DRAIN MORE THAN 30 DAYS
	100-199 DAYS	200-299 DAYS	300-400 DAYS	90-99 DS.	100-199 DS.	200-299 DS.	300† DS.	100-199 DS.	200-299 DS.	300-399 DS.	400-500 DS.	
EXERCISED	13	18	4	5	23	5	2	2	15	10	8	0
UNEXERCISED	18	12	2	2	26	4	0	7	17	4	4	0

CHART IV

It was noted that, if a result was graded *excellent* (joint possessing 120 degrees of motion or more), there was very little difference in the percentage of excellent results in the exercised and unexercised groups. In the treated group, twenty-one of eighty-eight (24 per cent.) were rated *excellent* and seventeen of seventy (24 per cent.) of the untreated were also rated *excellent*. In view of the previous statistical evaluation which showed the

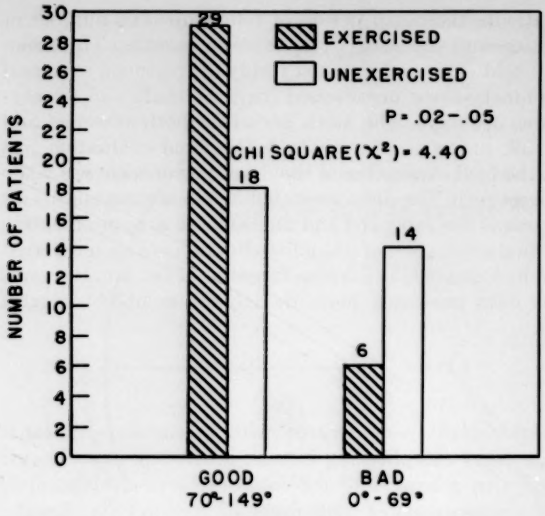

CHART V

results in the exercised group to be superior, a further breakdown of data was necessary to find where the ratings for the treated group gained significance. For this purpose the series was broken down into five groups as follows:

Failure	— 0 to 29 degrees
Poor	— 30 to 59 degrees
Fair	— 60 to 89 degrees
Good	— 90 to 119 degrees
Excellent	—120 to 149 degrees

This analysis revealed that the effectiveness of progressive-resistance exercises was predominant in preventing failures and in placing more in the *good* class (Chart II). The result statistically is not quite significant with a P value of .05 to .10; nevertheless it expresses a trend. This evaluation indicates that in a certain number of patients, an excellent result will be obtained regardless of the type of post-immobilization treatment, but that in others an excellent result will never be obtained regardless of the treatment employed. In this latter group progressive-resistance exercises will give a better result than conventional physical therapeutic procedures. The simultaneous strenuous stretching, production of hypertrophy, and pronounced vascular response, all present in such extreme degrees only in progressive-resistance exercises, are believed to account for the effectiveness of this type of exercise.

Thirty-one of the eighty-eight exercised patients gained complete extension on progressive-resistance exercises (Chart III). Another twenty patients increased extension on treatment, but did not recover it fully. Thus, fifty-one of the eighty-eight improved extension on exercise and, since twenty-five had normal extension initially, only ten failed to gain. Data were not available on two patients. The fifty-one patients had a mean extension gain of 12 degrees.

Four of the eighty-eight had complete flexion initially; therefore, eighty-four stood to gain on progressive-resistance exercises. All but six of these eighty-four made flexion gains. The mean flexion gain for the remaining seventy-eight was 30 degrees. The results in knee flexion are as follows:

	Before Progressive-Resistance Exercises	*After Progressive-Resistance Exercises*
Full flexion	4	12
Flexion to 90 degrees	24	58

It was felt that, for a more thorough evaluation of the group treated with progressive-resistance exercises, a more critical comparison should be made. Therefore, two similar groups were obtained in which the factors influencing knee motion were evenly distributed. Chart IV reveals the associated factors in the two sub-groups, such as type and location of fracture, form of traction, type of surgery, total immobilization period, absolute fixation, and time followed. There were thirty-five exercised patients and thirty-two unexercised. Each factor is well distributed throughout both groups. Chart V gives the results when 70 degrees is used as the dividing line between a good and a bad rating; again the rating is statistically significant. When each group is subdivided further into

five groups (Chart VI) and treated statistically, the probability value is not significant, but might well be if the number of cases were doubled, provided the same ratios were maintained [1].

This comparison represents the trend expressed in many comparable evaluations,—that is, the ratings in the exercised groups were significantly, or nearly so, better than in the unexercised group. This objective evidence combined with clinical experience furnishes undeniable evidence of the value of progressive-resistance exercises in the treatment of knees following fractures of the femoral shaft.

There were forty-one condylar fractures. Eighteen received progressive-resistance exercises and twenty-three did not. Statistical evaluation of the data revealed the exercised group not to be highly significant with a P value of .05 to .10 when subdivided into five groups (Chart VII) and a P value of .10 to .20 when subdivided into good and bad results (Chart VIII). Though this P value is not strictly significant, it indicates a trend in keeping with the results in similar evaluations previously described.

The effect of treatment on the eighteen condylar fractures is presented in Chart IX. Eight patients gained complete extension, nine gained flexion to 90 degrees, and three regained complete knee flexion. Further consideration of data shows that six failed to gain complete extension, four failed to gain flexion to 90 degrees, and fourteen did not recover full flexion.

Eleven of the eighteen exercised patients with condylar fractures registered extension gain on progressive-resistance exercises, and the mean extension gain for the eleven patients was 14 degrees. Of the remaining seven patients, four had complete extension prior to exercise and three failed to respond.

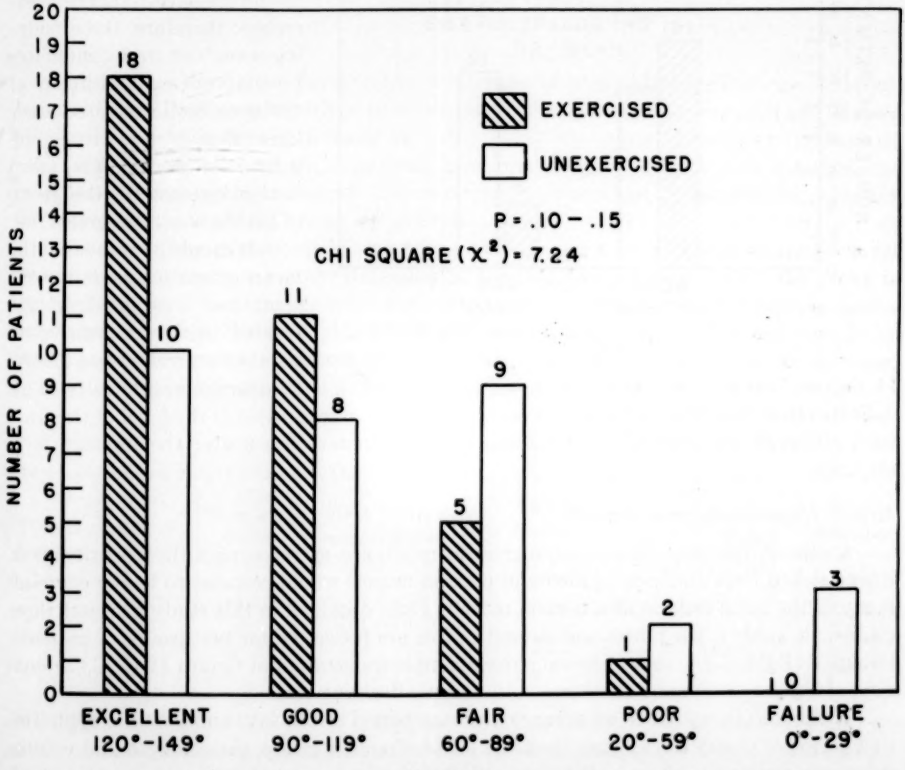

CHART VI

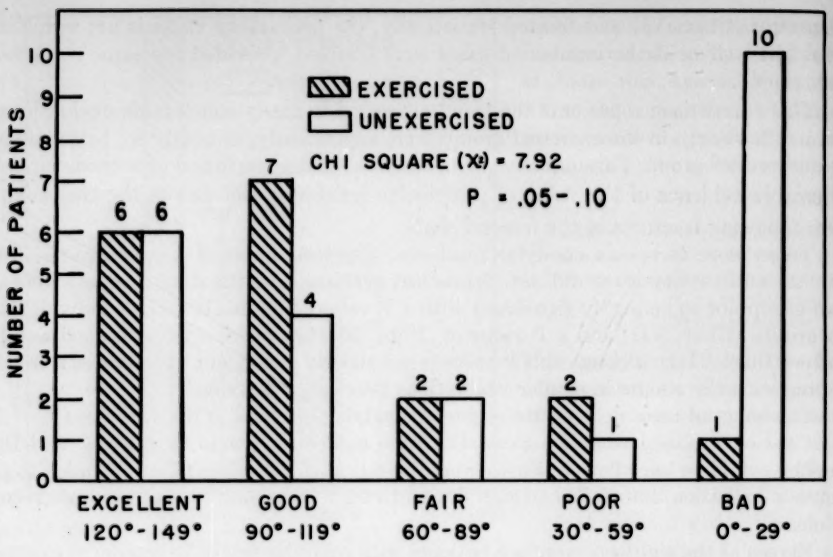

CHART VII

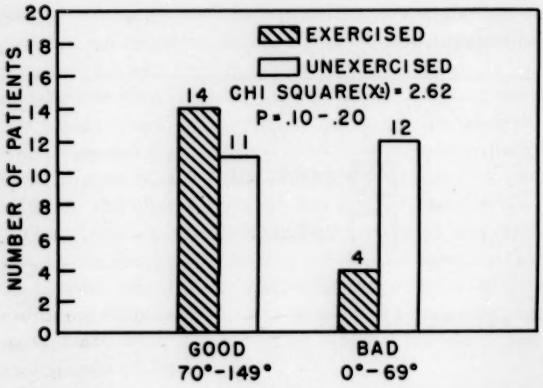

CHART VIII

Only one of the eighteen had complete flexion previous to progressive-resistance exercises; therefore, the remaining seventeen were candidates for improvement. Fifteen of the seventeen increased their knee flexion and three regained full flexion. The mean flexion increase for the group of fifteen was 38 degrees.

It should be noted that the mean extension gains for the shaft and condylar fractures treated with progressive-resistance exercises were 12 and 14 degrees, respectively, and flexion values were 30 and 38 degrees, respectively. This indicates that this type of treatment is equally effective regardless of the level of the fracture, although the residual joint motion steadily declines the nearer the fracture is to the knee.

Muscle Hypertrophy and Strength

In the initial publication on progressive-resistance exercises as a therapeutic agent, it was stated that disuse-atrophied and scarred muscle would respond to heavy exercises in much the same fashion as a normal muscle. Data obtained in this study bear out these claims. In Table I, the power and strength gains are presented for two groups of patients. Group I (F.S.C.) consists of twenty-three simple fractures, and Group II (F.C.C.) consists of sixteen compound fractures with chronic draining wounds.

Although Group II had an average drainage period of 163 days and a total immobilization period of ninety days longer than the simple-fracture group, the strength and volume gains are strikingly similar. Whereas, neither group represents normal muscles, both

responded in a normal fashion. The final quadriceps power of forty-one and twenty-eight pounds, respectively, is not within normal limits, but there is no reason to doubt that, if the period of progressive-resistance exercises had been continued, normal values would have been obtained. In fact, large numbers of these patients restored their 1 RM to normal levels, and in several instances the volume and strength of the injured thigh exceeded those of the uninjured.

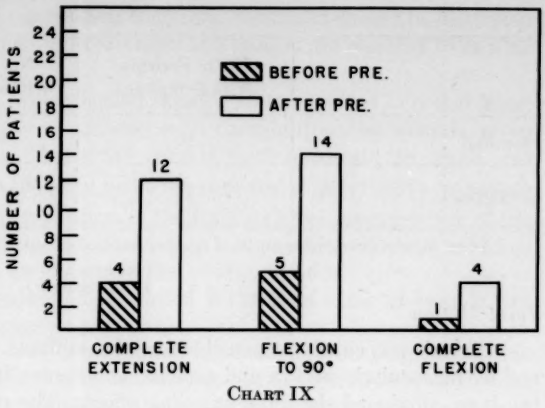

CHART IX

The fracture-simple-complete group (F.S.C.) had an increase of 273 per cent. in ten weeks of exercise, while the fracture-compound-complete group (F.C.C.) had an increase of 250 per cent. in seven weeks. This initial rapid rate of strength improvement could not, of course, continue indefinitely and substantiates the observations that on progressive-resistance exercises, strength gains at first are in excess of those that can be explained on the basis of hypertrophy.

The results illustrated in the two groups just discussed were typical of those seen in all groups. Therefore, further presentation of data would only constitute useless repetition.

Symptoms

Before final discharge, the presence or absence of pain, swelling, fluid, and crepitus was noted in a large number of the patients; and the results for the exercised and unexercised patients are presented in Table II.

Thus, 68 per cent. of those patients receiving progressive-resistance exercises had symptoms, and only 41 per cent. of the unexercised patients had symptoms. In Table III, the incidence of individual symptoms is cited.

The percentage of patients having pain, swelling, and fluid is strikingly similar in the two groups, but there is a great difference in the incidence of crepitus. Of the group of eighty-eight, twenty-one patients (24 per cent.) had crepitus as the only symptom, and of the sixty unexercised patients, only five (8 per cent.) had crepitus as their only symptom. It is this higher recorded incidence of crepitus that is chiefly responsible for the exercised group having a higher percentage of symptoms.

TABLE I *

Type of Fracture	No. of Fractures	Strength Gains (*Pounds*)	Final Strength (*Pounds*)	Increased Strength (*Per Cent.*)	Gain in Circumference (*Inches*)	Days on P.R.E.†	Drainage Period (*Days*)	Total Immobilization Period (*Days*)
F.S.C.	23	30	41	273	1	71	...	259
F.C.C. with Drainage	16	20	28	250	0.7	48	163	349

* All values are in group means.

† Progressive-resistance exercises.

TABLE II

	No. of Patients With Symptoms	No. of Patients Without Symptoms	No. of Patients Examined
Exercised	60	28	88
Unexercised	25	35	60 *

* Data were not available on 10 of the unexercised group.

DISCUSSION

Joint Motion

Fibrosis was chiefly responsible for joint stiffness. Scarring, occurring intracapsularly and extracapsularly and in and around the muscles, binding them to one another and to the bone, produced the most crippling effects. The reasons for the employment of progressive-resistance exercises in restoring joint motion have been described fully elsewhere [3]. The results of this study yield strong evidence that the combination of stretching, muscle hypertrophy, improved vascularity, and the "motor-learning" characteristic of such an exercise has a definite therapeutic value not obtainable with the less strenuous exercise techniques.

In many patients, normal knee motion was not obtained, but those who continued progressive-resistance exercises for an adequate period obtained normal strength. A powerful weight-bearing joint with limited motion is functionally superior to a weakly supported joint with a normal range of motion; and, since strength may be restored by exercising in a limited range, treatment should be continued until maximum power has been achieved and not stopped when motion fails to increase.

One particular advantage of the high-resistance exercises in restoring knee motion is the combination of simultaneous stretching and developing muscle strength. To achieve maximum function, strength must be developed to take full functional advantage of the motion gained by stretching. In many instances, motion gained by persistent passive stretching and light exercises alone is not retained after cessation of treatment, because the muscles are not sufficiently powerful to overcome the resistance offered by the fibrotic structures, and stiffness gradually returns.

Experience has left little doubt that there is a point beyond which the results of fibrosis are irreversible. Just when this occurs is not known exactly and no doubt varies greatly in different conditions. The patients in this study were, as a rule, placed on progressive-resistance exercises early in the ambulatory phase and the results were good, but those patients seen in civilian practice with similar fractures and limitation in knee function of long duration, usually of a year or more, almost routinely fail to increase perceptibly their knee motion by this or any other standard method. These patients are able, however, to build up quickly their quadriceps strength to a high level in the available

TABLE III*

	Pain	Swelling	Crepitus	Fluid	No. of Symptoms Present
Exercised	33 (37%)	11 (12%)	43 (49%)	0 (0%)	87
Unexercised	18 (30%)	5 (8%)	10 (17%)	1 (2%)	34

* As shown in Table II, 60 of the exercised patients had knee symptoms; however, in these 60 patients there were 87 knee complaints, thus many of the patients had multiple symptoms. The same is true of the unexercised group.

range. For maximum restoration of knee motion, therefore, treatment should be instituted as soon as union permits and continued until strength and motion are restored to as near normal as possible.

Paradoxically, simple fractures, which healed rapidly, often resulted in a stiff knee, while compound comminuted fractures, associated with chronic draining wounds, often healed with excellent knee function. This study reveals that, although the result was poorer the nearer the fracture was to the knee joint, the response to progressive-resistance exercises was approximately the same regardless of the fracture level. Appreciation of the fact that the integrity of the knee joint is dependent upon so many factors which influence return of knee-joint function aids in an understanding of this paradox.

Generally, it may be said that adhesion formation is the chief cause of trouble. Its presence in some areas is not so irreparable as in others. The site and degree of adhesion formation determines the amount of knee-joint motion regained. For the purposes of this discussion of knee function, adhesion formation is considered in relation to its involvement of the muscles and the joint. Fibrotic involvement of either the muscles or the knee joint may result in any degree of functional recovery. Some muscular fibrotic changes are irreversible and produce a stiff knee even though the knee joint itself, for all clinical purposes, is normal. Likewise normal thigh muscles cannot produce a well functioning knee if the capsule of the knee joint has contracted or if the patella is immobilized.

The factors influencing recovery, classified according to the site of adhesion formation, are as follows:

Muscle

1. Intrafascicular and interfascicular fibrosis;
2. Adhesion of muscles to each other and to the bone;

Joint

1. Contracture of the joint capsule due to adhesion formation;
2. Obliteration of suprapatellar pouch;
3. Adhesion of the patella to the femoral condyles;
4. Intra-articular adhesions binding the articular surfaces together.

These are not all of the factors responsible for influencing recovery, but they constitute the most important ones. It is difficult to rate these factors according to their importance in crippling effects, but clinical experience, in addition to information gained at surgery on twelve patients who had quadriceps-plasties and seventeen patients whose knees were manipulated under anaesthesia, suggests that certain factors are of greater consequence than others. Of the fibrosis involving muscle, the binding of the vastus intermedius to the femoral shaft is the chief offender. Once this has occurred, surgery is the only outlet. No amount of stretching will loosen the fixed muscles. The influence of scarring within the muscle itself is probably reversible. Many of the quadriceps muscles (in patients with knees normal by clinical examinations and roentgenograms) involved in this series were hard, indicating severe atrophy and fibrosis. As the muscle hypertrophied, the muscles softened, and there was a concomitant increase in joint motion.

Contracture of the capsule in the majority of the patients who had quadriceps-plasty seemed to be the chief limiting factor. No doubt there is a point beyond which contracture of the capsule is irreversible, but before this point is reached it may be stretched sufficiently to permit an increase in range. The area of pain described by patients whose knees were being strenuously stretched to regain flexion coincided with the portion of capsule pulled taut over the femoral condyles on manipulation of the exposed joint at surgery.

Once the patella has been bound to the femoral condyles, the process is irreversible and surgery is the only outlet.

Intra-articular adhesions involving the articular surface of the tibia and femur did not appear of major importance. Patients whose joints were limited mainly by this condition are believed to be those who benefited most by manipulation under anaesthesia.

Adhesion formation within the suprapatellar pouch influenced residual motion according to the extent and degree of fibrosis. If only a small area is involved, with a few fragile adhesions, the process is reversible; however, with complete obliteration of the pouch with heavy fibrosis, a poorly functioning knee results.

Thus we see that at different levels of the thigh there exist both irreversible and reversible conditions. In fractures far removed from the knee, intracapsular and pericapsular fibrotic changes may produce a stiff joint. In fractures involving the joint, with no injury to the thigh muscles, joint motion may be lost because of fibrotic involvement of the quadriceps femoris. These factors, combined with the normal individual variation in tendency toward fibrous-tissue reaction, explain, at least partially, the difficulty in predicting the outcome of treatment.

Muscle Hypertrophy and Strength

It must be stated that restoration of limb volume by muscle hypertrophy was not a primary aim in the treatment of these patients with progressive-resistance exercises except occasionally for cosmetic reasons. Many of the thighs had large muscle defects and hard, unsightly scars. In these patients hypertrophy was a primary objective to help fill in the defects and to soften the scars. The influence of progressive-resistance exercises on scars overlying muscles is striking. The combination of strenuous stretching, marked vascular response, and the mechanical effect of the expanding muscle undergoing hypertrophy rapidly produced a softer, healthier scar. This process can be applied to scars produced by burns as well as by mechanically inflicted wounds.

Frequently, it was noted that, before muscle volume had been restored to normal, the strength of the injured thigh would have equalled or even excelled that of the uninjured thigh. This led to the belief that muscle strength need only be restored to normal and that restoration of muscle bulk was unessential. Subsequent experience, however, has cast doubt upon the validity of this belief, for frequently patients who have regained power, but not bulk, seem to lose their gains in strength more rapidly than do those who have regained normal bulk, suggesting that strength due to increased efficiency of contraction subsides more rapidly without practice than does that due to hypertrophy of the muscle fibers.

It has been routinely noted that, after progressive-resistance exercises have been started, there is a rapid rise in strength over the first few weeks, followed by more gradual increments which may continue for months or even years. As Houtz pointed out, the initial improvement in strength is in excess of that which can be explained on the basis of morphological changes within the muscle. This initial rapid rise is most probably due to motor-learning. Thus there are at least two physiological processes responsible for strength improvement and the important clinical question is whether or not therapeutic exercises should be discontinued before normal bulk has been restored. If it can be established that normal bulk is essential for lasting strength, then the objectives of exercise therapy, especially progressive-resistance exercises, have been more firmly established. Ordinarily the exercise is continued until the strength is equal to that of the corresponding uninjured part, or to that of a comparable normal group, regardless of the atrophy present.

The data on limb-volume changes in these patients with fractured femora bear out the original claims that even the muscle most severely atrophied from disuse responds in a normal fashion to an overload exercise. None of the patients had any unfavorable reactions to the heavy exercises other than the customary initial transitory muscle soreness. No evidence was encountered to support the common claim that fatigue should be avoided in severely atrophied and scarred muscles.

Symptoms

The higher recorded incidence of crepitus in the treated group is understandable. Crepitus in the knees of these patients was looked for throughout the exercise period,

whereas in the unexercised group, it was noted only upon discharge. This symptom is more easily detectable when the knee is extended against heavy resistance; therefore, minor degrees of crepitation were detected in this group that probably would not have been picked up on a routine examination.

Crepitation, signifying roughening of the patellofemoral joint, was associated with two unfavorable aspects of the rehabilitation of these patients. Frequently it was accompanied by pain which retarded the response to exercise. However, this was not always the case as many with this symptom reached high strength levels unhampered by pain. Roughness reduces the mechanical efficiency of the patellofemoral joint [4]; therefore, quadriceps exercises had to be continued longer to produce sufficiently high levels of strength to overcome this disadvantage.

Crepitus was thought by some to develop on progressive-resistance exercises in a few patients, but it must be remembered that to detect crepitus the knee must move at least through a small arc of motion. There were patients who had severe restriction of motion initially (insufficient to demonstrate crepitus); and, as motion increased, the roughness already present manifested itself as crepitation. Since none of the patients developed more crepitation on exercise, there is no reason why the exercised and unexercised groups should have had any significant difference in the incidence of this particular symptom.

Pain was evenly distributed in the two groups, and was usually not an important symptom, being chiefly of the dull aching variety associated with weather changes. Some had more severe pain, but this was usually associated with crepitation, and only rarely was it of sufficient severity to prevent exercise. The heavy exercise, except as noted above, usually precipitated only a transient soreness about the thigh and knee, which disappeared within a week. Many patients experiencing knee discomfort obtained complete or partial relief while on progressive-resistance exercises.

Fluid was a negligible finding, and a few showed a slight periarticular thickening unassociated with demonstrable fluid. It usually subsided gradually and was not an important symptom.

The influence of progressive-resistance exercises on the joint symptoms described may be summarized as follows: Symptoms were not aggravated by heavy exercise except occasionally in the patient with severe patellofemoral roughening, and many experienced improvement.

SUMMARY

One hundred and fifty-eight soldiers with femoral-shaft fractures and forty-one with condylar fractures treated on the Orthopaedic Service of Gardiner General Hospital were subjects of an investigation to determine the effectiveness of progressive-resistance exercises in restoring knee function compared with that obtained by less strenuous physical therapeutic methods. Of patients with shaft fractures, eighty-eight received progressive-resistance exercises three weeks or more, and seventy did not. Eighteen of the forty-one patients with condylar fractures received progressive-resistance exercises while twenty-three did not. All data were collected immediately before discharge from general hospital care, which in this particular hospital included, in many instances, advanced reconditioning.

Results evaluated objectively provide strong evidence of the therapeutic effectiveness of this exercise technique over less strenuous methods. For optimum results it should be initiated as soon as union permits, and continued until maximum functional gains have been made. With caution, the exercises may be initiated at the end of the immobilization period. Progressive-resistance exercises are advocated as an adjunct to more conservative therapeutic procedures, for, when integrated properly in the rehabilitation period, a superior result will usually be obtained. It should replace the less strenuous exercises which are erroneously employed at this phase of recovery. Passive and light-resistance exercises

are of little or no value in the reestablishment of normal muscle bulk and strength without which rehabilitation of a fractured femur, or any other fracture for that matter, is incomplete.

The results of the study clearly indicate that as a whole, knee function, following battle-sustained fractures of the femur treated by the methods described, is not good and leaves much to be desired. The results, even in the simple, uncomplicated femoral fractures, should stimulate more interest in techniques, such as the intramedullary fixation, which would permit early ambulation to preserve knee-joint motion.

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OSTEITIS PUBIS WITH INVOLVEMENT OF THE HIP JOINT

BY Z. B. FRIEDENBERG, M.D., PHILADELPHIA, PENNSYLVANIA

From the Department of Orthopaedic Surgery,
Hospital of the University of Pennsylvania, Philadelphia

Osteitis pubis is generally considered an affection limited to the pubis and the ischium, developing as a complication of suprapubic prostatectomy. This report concerns a patient in whom osteitis pubis followed a prostatectomy, and subsequently the process involved the hip with gradual destruction of the joint. A survey of the literature has brought to light only one other such report.

Beer, in 1928, published the first description of osteitis pubis. Since then, sufficient reports of this disease have appeared, mostly in urological journals, to indicate that it is not a rarity. Of 174 patients who had suprapubic operations, Kirz noted this complication in 3 per cent. Moore reported eight instances of osteitis pubis in forty-six cases (17 per cent.) of retropubic extravesical prostatectomy. Kleinberg reported a case in a woman with pyelonephritis who had not undergone surgery, but who had involvement of the anterior portion of the pelvis resembling osteitis pubis. Lavalle and Hamm found forty-one reported cases of osteitis pubis prior to 1949. The disease frequently remains undiagnosed, particularly in those with mild symptoms.

Osteitis pubis is most commonly seen after suprapubic prostatectomy and appears to be a low-grade inflammatory process, beginning in the symphysis pubis and migrating laterally to the rami of the pubis and ischium. Clinically, there is a gradual onset of severe pain in the region of the symphysis pubis, which radiates to the suprapubic area and the

adductor surfaces of the thighs. The pain usually begins ten days to two months after an operation upon the urinary bladder. A low-grade fever and leukocytosis may accompany the onset of symptoms. Severe spasm of the adductor group of muscles may occur; the anterior portion of the pelvis and the adductor muscles are tender. The hips have a full range of motion, but complete abduction may be painful. Such findings persist from three to twelve months and then gradually subside; a complete cure is usually obtained. Roentgenographic changes appear about three weeks after symptoms have been noted. The symphysis appears widened; the bone structure has a moth-eaten appearance and there is periosteal new-bone formation. Such changes may be confused with metastatic carcinoma, but they remain symmetrically confined to the anterior segment of the pelvic girdle and no osteosclerosis develops. Complete bone restitution occurs, but the symphysis may show residual bony ankylosis.

The etiology of this condition is in dispute. Beer, Muschat, Kirz, Goldstein and Rubin, Peirson, Silver, and Kleinberg believe a low-grade sepsis gains entrance to the symphysis after trauma to the bone from retractors, tubes, or drains, and then spreads subperiosteally. Wheeler could not produce the disease in rabbits by injecting mixed cultures of pyogenic organisms after trauma to the periosteum of the anterior pelvis, and he concluded that the disease was a form of Sudeck's atrophy.

Kretschmer and Sights reported a case in which sinuses discharged pus from tracts leading to each ischial tuberosity. The organism was not noted. Muschat reported a case in which the symphysis was curetted and showed subacute osteomyelitis; *Bacillus proteus* was cultured from the curettings. Other cases have been reported with positive urine and blood cultures, the organisms being *Escherichia coli*, hemolytic *Staphylococcus aureus*, or *Bacillus proteus*.

No specific treatment is known. Deep roentgenotherapy, diathermy, antibiotics, and vitamins have been employed. The patient is usually made comfortable by immobilization in a bilateral hip spica extending to the knees. In the vast majority of cases the disease is self-limited, and most authors state that no serious consequences will ensue and no other structures will be involved.

The following report concerns a patient whose course was typical of osteitis pubis; later suppurative arthritis of the hip developed with marked destruction of the joint and complete disability.

The patient, a man, sixty-four years old, was admitted to the Orthopaedic Department of the Hospital of the University of Pennsylvania on June 6, 1948. A two-stage suprapubic prostatectomy had been done at another hospital six weeks previously for benign hypertrophy of the prostate. He complained of pain localized over the symphysis pubis, radiating to the right inguinal region. This pain, of two weeks' duration, prevented him from standing erect and forced him to walk with short, shuffling steps. Physical examination showed a well-healed suprapubic scar which was not tender. There was tenderness over the symphysis and in the right inguinal region. The adductor muscle group on the right was in mild spasm, but both hip joints could be moved through a normal range of motion. There was no elevation of temperature, and the remainder of the examination was negative.

Urinalysis showed a large number of pus cells; Pseudomonas and non-hemolytic Streptococci were grown from urine cultures. There were no red cells, casts, or albumin. The white-blood-cell count was 8,800; the differential count was normal. Roentgenograms showed some mottling of the pubic ramus on the right (Fig. 1).

The diagnosis was osteitis pubis. The patient was made comfortable by a bilateral hip spica to the knees, with the hips in 20 degrees of abduction. He was discharged on June 21.

This man was admitted to the Urology Service on July 14, because of recurrence of pain, which radiated into both thighs medially. Intravenous urograms showed no disturbance except for the persistent pyuria. Roentgenograms showed widening of the symphysis pubis and some fragmentation of the adjacent bone. The spica was removed, and the patient received a five-day course of penicillin, totaling 2,500,000 units. When discharged on July 18, he was improved and was ambulatory.

Eight months later, on March 24, 1949, he was readmitted to the Orthopaedic Department. The pain over the symphysis had disappeared, and the pubic and ischial areas were only slightly tender. The chief complaint was pain, localized to the region of the left hip and radiating to the lateral aspect of the thigh. Weight-bearing on the left was said to have been painful for the last two months. There was one-half inch of

atrophy of the left thigh. Motion of the hip, which had been normal at the previous admission, showed complete loss of abduction, adduction, and internal rotation, presumably due to marked spasm. External rotation of the hip was possible to 45 degrees, flexion to 70 degrees, and extension to 170 degrees. The temperature was not elevated.

FIG. 1

Roentgenogram of the hips at the time of first admission.

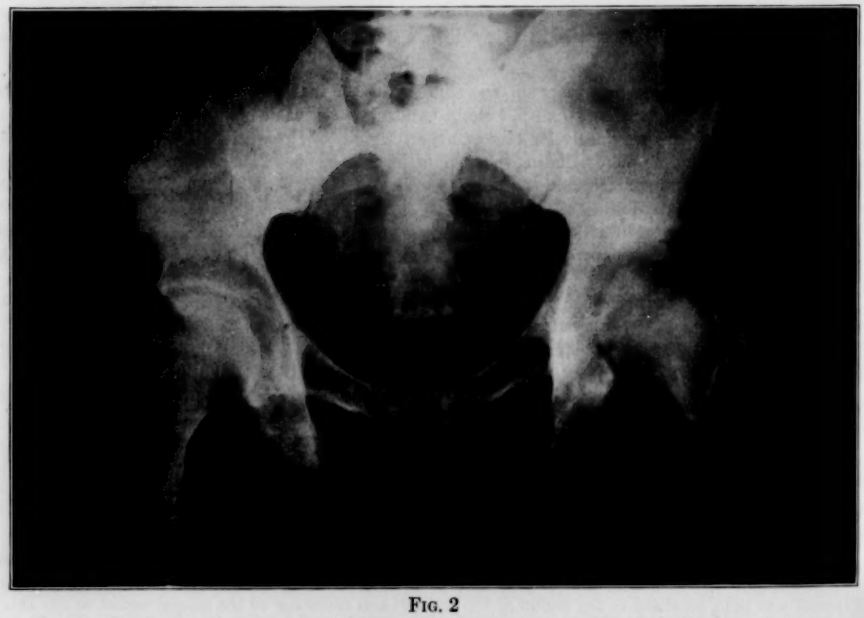

FIG. 2

Showing destructive changes in the left hip joint, which were found ten months after admission.

Roentgenographic examination showed marked destruction of the joint space and of the superior acetabular rim of the left hip. An extensive laboratory and roentgenographic survey uncovered no new findings. On six occasions during this admission Pseudomonas was cultured from the urine; on two occasions it was associated with *Staphylococcus albus*.

On April 13, 1949, a biopsy of the hip was done. The capsule was thickened and, on opening it, a small amount of thin pus escaped. The cartilage of the femoral head had lost its glistening appearance; it was fibrillated and in places was detached from the underlying bone. A culture of the pus grew Pseudomonas. Microscopic study of cartilage removed from the femoral head showed some fibrillation. Postoperatively the patient was comfortable in a hip spica. Streptomycin (0.5 gram twice daily) and penicillin were administered for six weeks. Roentgenograms showed a rapid increase of the destructive process (Fig. 2), and an extra-articular fusion of the hip was decided upon.

A large cortical graft from the tibia was placed between the femur and the ischium, just inferior to the lesser trochanter, according to the method of Trumble. The patient was immobilized in a bilateral spica, extending to the knee on the uninvolved side. He remained free from pain, and follow-up roentgenograms revealed satisfactory progression of the fusion without further extension of the inflammatory process. Seven months after operation, a fracture of the graft necessitated further immobilization.

COMMENT

In two of Silver's patients, hip symptoms developed three to five months after suprapubic cystostomy. Both showed narrowing of the joint space with restriction of motion. The disease was arrested in both cases without operative intervention.

In the patient reported here, osteitis pubis and a suppurative arthritis with involvement of the acetabulum and the head of the femur developed, despite institution of early and vigorous treatment. An eight-month interval elapsed between the suprapubic prostatectomy and the development of hip pain, during which period his original complaints referable to the anterior pelvic region completely disappeared. The course of the disease, both clinically and roentgenographically, resembled a low-grade osteomyelitis. Pseudomonas was cultured from the urine on numerous occasions over a period of more than eighteen months, and the same organism was cultured from pus from the hip joint.

Our present concept of this disease as a localized, self-limited process confined to the anterior pelvic girdle should be altered. It is possible that less dramatic changes in the hip joint, occurring long after the initial period of this disease, are being overlooked.

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CHRONIC OSTEOMYELITIS

Primary Closure Following Saucerization

A Preliminary Report

BY BRANDON CARRELL, M.D., AND J. W. WOODWARD, M.D., DALLAS, TEXAS

From the Texas Scottish Rite Hospital, Dallas

INTRODUCTION

The chart files of many hospitals are stacked high with the voluminous records of those unfortunate individuals who fell heir to chronic bone infection. In many case records, the recent history of the treatment of the condition can be traced. Even records not too yellowed with age tell of the efforts to effect a cure by the use of maggots and, on subsequent recurrences, by the introduction of the tedious Carrel-Dakin method; after a few more years came the Orr technique, which was somewhat more satisfactory but had many drawbacks. The thickness of these charts indicates the many weeks and months of hospital care, but is not adequate testimony of the pain and suffering associated with those weary days.

With the introduction of the sulfonamides and then a bit later of penicillin, all associated with these cases held hope that at last some progress could be made in the treatment of both the acute and the chronic infections. Time has borne evidence that these drugs have a profound effect in the acute case, but seldom give permanent benefit in the old established case. It is recognized by all that antibiotics are blocked from the site of activity by the extreme avascularity presented in the average case of chronic osteomyelitis. Many of these patients have had repeated operative procedures over a period of many years with the result that the surrounding soft tissues have been transformed into a dense fibrous mass, beset with sinus tracts and adherent scars. The bone itself shares in the picture, with a dense sclerotic cortex harboring sequestra and areas of pus and granulation tissue.

In 1935, Lord presented the idea of a thorough removal of the diseased tissue, filling the bone cavity with muscle or fat, and then closing the wound tightly to try to effect a primary healing. Various means were used to shift flaps of skin for plastic closures of the defect.

Buchman and Blair made a careful study of the effect of penicillin on chronic osteomyelitis, both with and without surgical measures. It was made evident that the secondary invaders, predominantly *Bacillus proteus* and *Bacillus pyocyaneus*, which abound in the wounds of those treated by the Orr method, were not markedly retarded by penicillin therapy. The healing was not hastened, the primary organisms assumed a resistance to the drug, and in cases of secondary closure the wounds tended to break down. Their preliminary reports were highly in favor of primary closure of these wounds.

MATERIAL FOR STUDY

The search for a better method of treatment led the staff of the Texas Scottish Rite Hospital to adopt the primary-closure technique. During a period of five and one-half years, beginning April 1944, a total of forty-one cases have been so treated; forty-nine operations have been performed.

It should be pointed out that this is a preliminary report, since a far greater time interval is needed to pass final judgment on the value of the treatment in chronic osteomyelitis. At a later date further data will be obtained to complete these case analyses.

The average duration of symptoms prior to this type of treatment was four years

and three months. Of the forty-one patients, 27 per cent. had undergone one or more surgical procedures previously. The average age in the series of twenty-six boys and fifteen girls at the time of operation was eleven years and nine months. The average duration of follow-up was two years and three months. In thirty-nine of the cases, the onset was as acute hematogenous osteomyelitis; in one, the osteomyelitis was a complication following an open rotational osteotomy of the tibia; in the other case, the infection of the femur appeared with Hand-Schüller-Christian disease. Roentgenographic evidence of sequestra was found in 73 per cent. of the cases. Cultures taken prior to or at the time of surgery showed *Staphylococcus aureus* in 60 per cent., *Staphylococcus haemolyticus* in 8 per cent., *Streptococcus viridans* in 8 per cent., and no growth in 24 per cent.

TECHNIQUE EMPLOYED

The surgery was performed by the senior residents under the direct supervision of the attending staff. Basic surgical principles were as follows:

1. Removal of all devitalized and infected bone by conservative saucerization of the bone, avoiding overhanging edges, and opening to normal medullary cavity above and below.

2. When possible, removal of avascular soft tissue, including adherent scars and sinus tracts.

3. Primary closure of the wound, aimed at bringing vascular soft tissues into the space created by the saucerization and approximating the skin edges to avoid invasion by secondary bacterial flora.

With the exception of the first four cases in the series, all patients received penicillin for two to three days prior to surgery and for as long following as conditions indicated, generally for seven to ten days. In a few of the early cases, one of the various sulfonamides was used in a like manner. The operations were performed with the benefit of a tourniquet; major vessels were ligated with fine catgut when necessary. After saucerization, the wounds were generally washed with green soap, irrigated with a copious amount of saline, and then treated by flushing with a small amount of ether; finally this was removed by a second saline irrigation.

Closure technique was designed to fill the bone defect with vascular soft tissue, a minimum of suture material being buried. In a few instances, fine catgut was used in fascia, but generally all layers were brought together with several deep figure-of-eight sutures of No. 30 cotton. Skin edges were further approximated with interrupted mattress or interlocking running stitches. In eighteen cases, the wounds were closed tightly, after sulfanilamide crystals had been lightly frosted in the wounds. In sixteen, the wounds were closed tightly around a small soft-rubber catheter, used to instill a penicillin solution for three to four days postoperatively. Fifteen wounds were closed tightly without benefit of local antibiotics.

Voluminous dressings were applied, and held firmly in place by elastic bandages. Generally the wounds were inspected in three to four days, at which time any excessively tight sutures were released, and the catheter, if present, was removed. The bulky bandages were then reapplied. Plaster encasement was necessary in three cases as insurance against fracture after removal of large sequestra.

RESULTS

Statistics do not reflect the very important decrease in treatment-produced pain and the heart-warming improvement in morale in these children, as compared with those under other routines. The time required by physician and nurse to care for them is also gratifyingly short.

In this series of cases, healing by primary intention took place in 82 per cent., in an average time of 13.1 days. These wounds healed in their entirety; those breaking down in

FIG. 1-A
July 21, 1947

FIG. 1-B
September 10, 1947

FIG. 1-C
August 10, 1949

B. J., aged twelve. Onset of disease in January 1947; operation in July 1947. Wound failed to heal primarily in lower one inch. Sear became adherent and was resected one year after saucerization. No evidence of recurrence after two years.

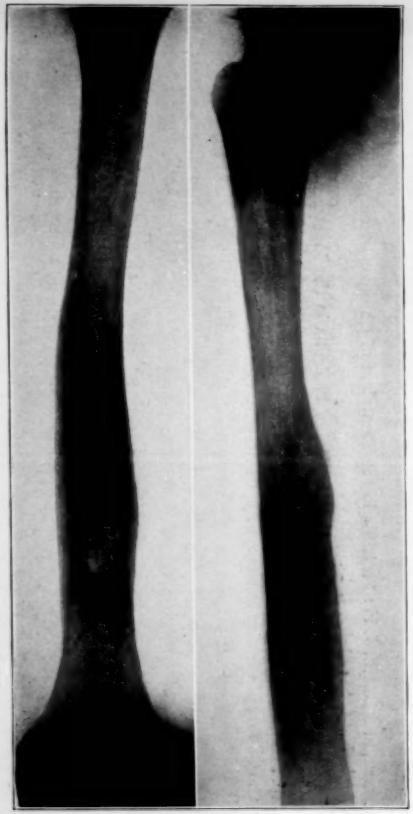

FIG. 2-A
November 28, 1945

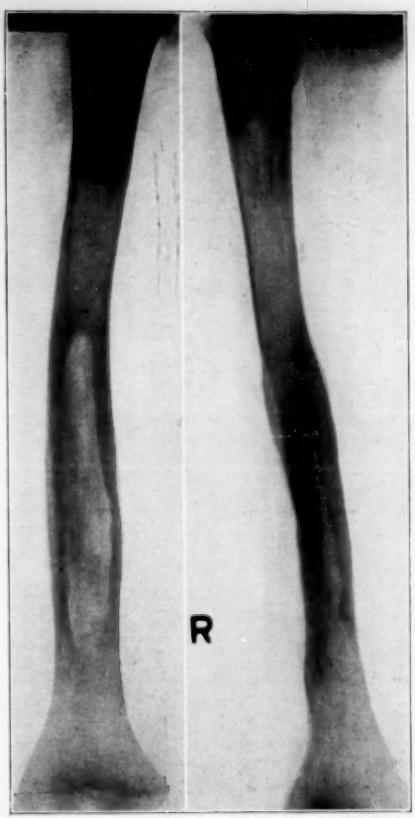

FIG. 2-B
March 14, 1946

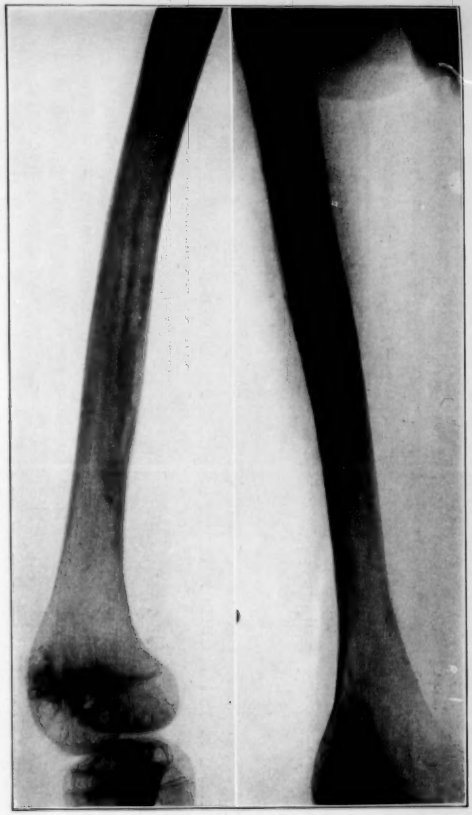

FIG. 2-C
July 9, 1947

B. G., aged thirteen. Onset of disease in August 1944. Operation in December 1945. There had been multiple sinuses for which there had been three drainage procedures. Sutures were removed in eleven days. There was scant drainage from tract of the catheter for two months. A recurrence in the greater trochanter region, six months after saucerization of the lower portion of the femur, was treated by routine method. No further surgery has been required.

TABLE I

RESULTS OF PRIMARY CLOSURE FOLLOWING SAUCERIZATION

Location	No. of Cases	Primary Healing	Secondary Healing
Femur	15	11	4
Tibia	19	15	4
Humerus	6	6	0
Radius	3	3	0
Ulna	3	2	1
Ilium	2	2	0
Ischium	1	1	0
Total	49	40	9

only a segment of the incision were classified as healing by secondary intention. The average hospital stay was fifteen days, as compared with twenty-seven days in the nine cases in which healing was not satisfactory. In those cases where breaking down in all or part of the incision occurred, healing took place in an average of seventy-five days, which compares favorably with those treated by the Orr technique. Seven of the nine cases in which breaking down of the wounds occurred were in the first two years of the series. There have been only two failures in the last thirty-seven cases.

Some degree of recurrence was noted in 40 per cent. during the follow-up period, which averaged two years and three months. Additional surgery was necessary in 16 per cent.; in the other cases, the recurrences were controlled by antibiotics, rest, and the application of heat.

Before compiling the results, it had been felt that those cases in which a rubber catheter had been used to instill penicillin were more prone to failures in healing. It was found, however, that primary healing took place in 87 per cent. of that group, as compared with 72 per cent. in those closed with sulfanilamide in the wound, and 86 per cent. in those closed tightly with no local antibiotic.

CONCLUSIONS

Primary closure of the wound following saucerization procedures in chronic osteomyelitis resulted in primary healing in 82 per cent. of a series of forty-nine cases.

This technique is dependable and has outstanding advantages to both the patient and those attending him.

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VACUUM PNEUMARTHROGRAPHY AND THE SPONTANEOUS OCCURRENCE OF GAS IN THE JOINT SPACES *

BY DELLIVAN M. FUIKS, M.D., AND CHARLES E. GRAYSON, M.D.,
SACRAMENTO, CALIFORNIA

The occurrence of gas in joint spaces is not particularly unusual and is generally considered of little or no significance. The production of low pressure in the joint by traction releases gas from the adjacent tissues into the space, which is thus visible by contrast roentgenographically. Sufficient amounts have been produced by decompression [19], as in "bends", for quantitative analysis. The gas is a mixture of oxygen, carbon dioxide, and nitrogen, in proportion similar to that of the circulating blood.

Fick observed this phenomenon in 1910, while studying joints under traction. Later reports [2, 4, 12, 14] mention the same occurrence (Fig. 1) in other joints. Most of us have observed this vacuum phenomenon or have produced it inadvertently; it is usually referred to as "cracking knuckles". The vacuum is seen frequently in the shoulder joints of infants whose arms are held over the head while a chest roentgenogram is being exposed.

FIG. 1

In a girl, aged fifteen months, traction was applied to the lower extremity during roentgenography to produce a symmetrical position of the femora. The opposite acetabulum was 4 millimeters deeper.

Widmann and Stecher reported gas in the joint space in two patients with injured shoulders. Nordheim showed that this could be produced by external rotation of the humerus. He also demonstrated in the knee joint that the gas is replaced by fluid within ten minutes, if constant traction is applied. Therefore, it is obvious that the situation can be only temporary and is not due to injury. The authors' own observations (Figs. 2-A, 2-B, 2-C, and 3) are corroborative. This form of internal force is occasionally seen in the wrist joint when it is in the position of ulnar deviation without traction.

Evans stated that the spontaneous occurrence of the vacuum phenomenon in the knee had been observed by Dittmar, who also used forced abduction of the knee to demonstrate the joint space. He believed the condition to be an indication of relaxed collateral ligaments. Others [12] have observed the same findings in presumably normal and in arthritic knees.

The authors' observations include four instances in which the medial joint space was visible with the knee extended and the muscles relaxed. In one of these a badly frayed meniscus was evident by vacuum technique, two had numerous loose bodies, and one showed deformity of the cartilage surface associated with hypertrophic arthritis. The same abnormality has been observed in sixteen knees, examined with the patient in the kneeling position.

With one exception, the space was visible only in the knee of which the patient com-

* Read at the meeting of the Western Orthopaedic Association, San Francisco, California, November 1948.

FIG. 2-A

FIG. 2-B

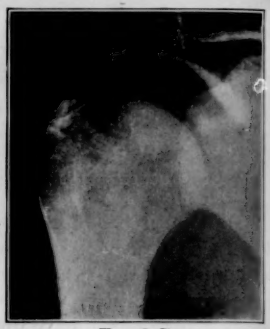

FIG. 2-C

Three adults with painful shoulders were examined.
Fig. 2-A: The patient's hand had been caught in a belt with severe traction, three hours before.
Fig. 2-B: The patient had received a blow to the shoulder, ten days before.
Fig. 2-C: Shows a calcareous deposit in subdeltoid region, in a patient, aged thirty-three years. There had been no injury.
Note: The space is visible with arm in external rotation only.

FIG. 3

A male, aged sixteen years, had limited scapular motion following injury incurred when he was an infant, but no pain. Shows axillary projection with humerus in maximum abduction.

plained (Figs. 4-A and 4-B), whether or not there was associated injury. The opposite knee, always examined simultaneously, served as a control. Five of these knees showed arthritic changes. A thinned and frayed medial meniscus was demonstrated in one instance. No abnormality could be demonstrated in the other ten. In the one exception, the phenomenon was present in both knees. In this case, instability of the knees due to laxity of the cruciate ligaments could be demonstrated by physical examination. It is our impression that the laxity of the posterior cruciate ligament allows the femoral condyle to glide forward on the wedge of the meniscus, thus widening the joint space and producing the vacuum. No particular significance is attached to the abnormality.

Forced abduction or adduction of the knee joint for diagnostic purposes is of limited value, but the expediency and simplicity of the procedure warrant its use. Since the joint space cannot be demonstrated in the presence of fluid, the value of the manipulation is limited to the indication of small amounts of fluid [7, 16] not perceptible by physical examination. Felsenreich demonstrated subluxation of the medial meniscus by this method, but believed the procedure to be of little value. Evans believed the method to be of some help in diagnosis.

It seems paradoxical that meniscus abnormalities should be considered insignificant when demonstrated by vacuum technique, if they can be demonstrated almost as well as by the injection of gas, and abnormalities disclosed by gas injection are considered diag-

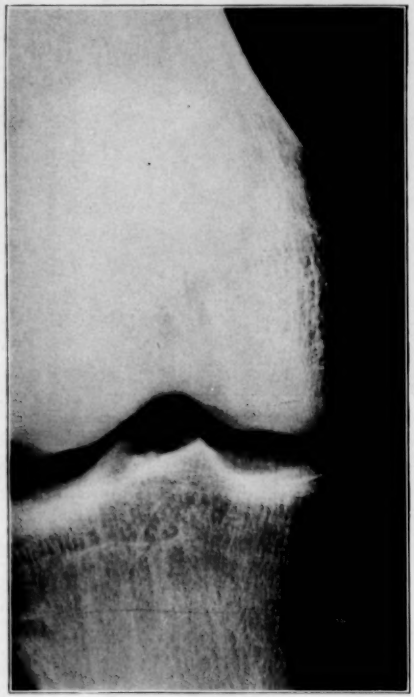

FIG. 4-A

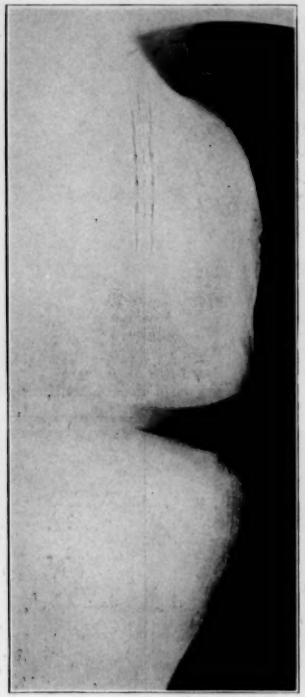

FIG. 4-B

A male, aged seventeen years, had had traumatic dislocation of the patella, four years before. There was persistent pain over medial aspect of knee.

Fig. 4-A: Spontaneous gas line is seen with limb in kneeling position.

Fig. 4-B: Vacuum pneumarthrography demonstrates normal meniscus and absence of fluid.

FIG. 5

Cleft in lumbosacral intervertebral space is demonstrated by moderate hyperextension. Patient has healing compression fractures of first and fourth lumbar bodies. Spine had been fixed by external splinting for three months, obviating any recent injury.

nostic. However, the excellent and comprehensive studies by injection technique [1, 9, 10, 13, 15] are invaluable in avoiding erroneous interpretation of irregularities noted by either method.

By simple hyperextention, the vacuum technique demonstrates clefts or fragmentation in the intervertebral discs [8, 11, 14] (Fig. 5), always associated with narrowed intervertebral spaces and hypertrophic spurs [17]. The authors have seen this abnormality in fourteen instances of pain in the spine, some without history of injury and a few following injury. Obviously the bone changes alone suggest a disease process of long standing. However, the demonstration of a fragmented disc is an indication that there is actually more than simple decrease in the substance.

FIG. 6

A male, aged nineteen years, had low-back pain. At routine examination, the vacuum phenomenon was observed in articular-facet joint of lumbar spine.

The authors have seen a thin gas line in four sacroiliac joints, and there is presumptive evidence that this

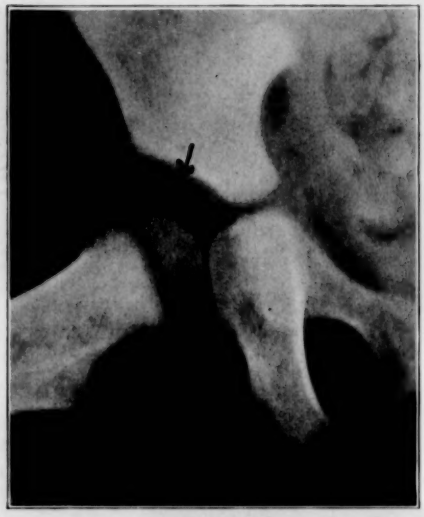

FIG. 7-A

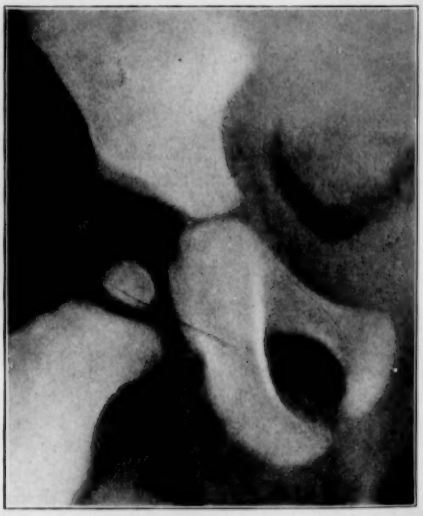

FIG. 7-B

A girl, aged one year, who was beginning to walk, favored her right lower extremity.

Fig. 7-A: Showing spontaneous vacuum phenomenon.

Fig. 7-B: Smooth cartilage was demonstrated by traction. Acetabulum is more shallow than average, and slightly more shallow than that on the opposite side. Note the difference in amount and configuration of gas meniscus has produced spontaneously and by traction.

is the same phenomenon which occurs in other joints. The line was no longer evident on a similar comparison film taken ten minutes later, although the patients remained supine and immobile in the interim. The spinal apophyseal joint space can be similarly demonstrated in oblique projections with torsion of the spine, such as are done in some orthopaedic manipulative procedures.

During a routine examination of the spine, passive torsion was used on the lower portion of the spine for oblique views. In this instance, the vacuum phenomenon was observed in a zygapophyseal joint in the lumbar spine (Fig. 6).

The spontaneous occurrence of a vacuum space in the hip joint appears to be of some diagnostic importance. The normal configuration of the articular surface of the head of the femur is a segment of a true sphere. Under this condition only can the articular surfaces be in contact throughout all of the normal range of motion. When the surface is altered in any manner, the potential space becomes a true space, filled with gas under low pressure or with fluid. This has been observed in six instances (one case of arthritis not being included) with the femur abducted and externally rotated; this is the position farthest removed from the habitual position and, therefore, produces the greatest lack of conformity which is still present under a lesser range of motion, but is not demonstrable roentgenographically. This phenomenon permits detection of minimal abnormalities of the cartilaginous surfaces (Figs. 7-A and 7-B), not otherwise appreciated. The irregularity of the cartilaginous surfaces thus demonstrated may be an important factor in the production of the pain and later disability which occur in these abnormal joints.

SUMMARY

Limited information is gained by vacuum pneumarthrography of the knee.

1. Absence of the vacuum space indicates fluid which may not be detected otherwise.
2. The meniscus can be demonstrated in the absence of fluid. Neither weakening nor relaxation of the ligaments is a prerequisite.
3. Pathological irregularities of the meniscus and articular cartilaginous surface can be identified.
4. Visualization is limited to the rigid structures and does not include synovial extensions or fat pads, as does the injection technique.
5. The examination can be done simply, quickly, and without the use of surgical technique or apparatus.

Spontaneous vacuum phenomena occur only in abnormal hip joints and demonstrate irregularities of the cartilage which would otherwise not be perceptible by roentgenographic examination.

This is a preliminary report only, which is submitted to stimulate interest in the possible clinical significance of the vacuum phenomenon.

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CHONDRODYSTROPHIA CALCIFICANS CONGENITA

CASE REPORT WITH AUTOPSY FINDINGS

BY EDWARD J. COUGHLIN, JR., M.D., HOWARD T. GUARE, M.D., AND ABRAHAM J. MOSKOVITZ, M.D., BENNINGTON, VERMONT

From the Putnam Memorial Hospital, Bennington

The condition which Raap named "chondrodystrophia calcificans congenita" is still enough of a rarity to warrant the report of individual cases. Since the condition was first described by Conradi in 1914, at least eleven cases have been reported. As pointed out by Vinke and Duffy, the condition has been considered by many to be a form of achondroplasia. It has been referred to as "stippled epiphyses", and some confusion has arisen as to its relationship with cretinoid epiphyseal dysgenesis. Probably because of this confusion, thyroid extract has occasionally been advised for therapy.

Detailed reviews of the literature on the subject have recently been made by Borovsky and Arendt and by Vinke and Duffy. It is of significance to note the predilection for multiple congenital abnormalities. In Tisdall and Erb's case, a patent ductus arteriosus was found. Lightwood, Bateman, and Maitland reported congenital cataracts. In the authors' own case, there was an associated cleft palate. Flexion deformities were noted in the cases of Tisdall and Erb, Borovsky and Arendt, Bloxsom and Johnston, and in the authors' case.

In none of the cases reported has there been a maternal history of rubella or of other exanthemata during the early months of pregnancy. However, some of these cases were reported prior to publication of the work of Gregg. In our own case, we were unable to obtain any history of exanthemata during pregnancy.

CASE REPORT

A seventeen-year-old white woman was admitted to the Hospital on July 10, 1947, for delivery of her first child. She had had the usual childhood diseases, but no operations. Menstruation had started at fifteen years of age; subsequent periods had been normal.

The family history was essentially negative, except that one brother had been born with a cleft palate.

In the antenatal period the patient had had no illnesses, except for occasional slight flowing. The Eagle test was negative. Her measurements were normal prior to admission to the Hospital. There had been a gain of nineteen pounds during pregnancy.

Physical examination revealed a fairly well developed and nourished woman at full-term pregnancy, with a cephalic presentation. Labor began spontaneously and, after eight hours, the mother delivered what appeared to be a premature female child, weighing four pounds and twelve ounces. Convalescence was uneventful and she was discharged from the Hospital on July 19.

Immediately after birth, it was noticed that the child had a cleft palate. She was frail and lay with the elbows flexed and the hands pronated. The hips and knees were flexed, and it was difficult to extend the arms and legs. The child was given vitamin B, vitamin K, and cod-liver oil. Because of the cleft palate, she was fed by gavage.

It was felt that the baby had some bizarre form of achondroplasia, and roentgenograms were taken on July 17 (Figs. 1, 2, and 3). They were reported as follows:

"Films of the entire skeleton show symmetrical distortion of the size and shape of the long bones, together with peculiar changes in the regions of the ossification centers. The over-all appearance is that of achondroplasia with shortened, thickened long bones, especially in the lower extremities. Our interest centers on the joint spaces of the skeleton. In the upper and lower extremities there are irregularly shaped, densely stippled masses in the region of all the epiphyses. These areas are also irregular in density, suggesting calcific deposits, together with either cartilage or non-opaque tissue elements. There are a few small calcific deposits in the soft tissues surrounding the joint spaces. The stippled appearance is seen in all sites and centers of ossification. The changes mentioned suggest some unusual type of foetal achondroplasia."

The child did fairly well until September 2, when she began to run a high temperature. A diagnosis of pneumonia was made, which was confirmed by roentgenogram. In spite of antibiotics and fluids, she died on September 3.

The laboratory findings were as follows: blood calcium 13 milligrams per 100 cubic centimeters, alkaline phosphatase 18 King-Armstrong units, and inorganic phosphorus 23 milligrams per 100 cubic centimeters (only one reading was obtained).

The roentgenograms of September 2 were reported as follows: "Films of the chest show a patch of extra density in the right upper lobe, which is probably pneumonitis. The left lung is partially collapsed. There are also epiphyseal changes due to the achondroplasia."

Autopsy Findings

Postmortem examination showed a fairly well developed white female infant whose total length was 42 centimeters. The measurements of the upper extremities were identical, as follows: from the tip of the acromion process to the radial dimple, 6 centimeters; from the radial dimple to the tip of the radial styloid process, 6 centimeters; from the tip of the radial process to the tip of the middle finger, 5 centimeters. The distance from the tip of the greater trochanter to the knee was 9 centimeters, and from the knee to the sole of the foot, 10 centimeters. The forearm was flexed on the arm at about 45 degrees on each side. The hand was flexed on the forearm at 90 degrees. It could be forcibly extended to about 45 degrees. The thighs and knees were flexed in similar manner at about 45 degrees. The pupils were round, equal, and measured 0.3 centimeter in diameter. The soft palate was separated for a distance of 1 to 2 centimeters; the cleft extended as far as the hard palate. No other congenital anomalies were found. The chest was well developed. The abdomen was moderately distended and tympanitic.

The pleural surface of the left lung was smooth and glistening. The lung was fully expanded and crepitant. The cut surfaces were salmon-colored and mottled with numerous small dark-red areas; some of these were of firm consistency, suggesting atelectasis. These areas were not numerous. On pressure a small quantity of white, frothy fluid was exuded. The bronchi and bronchioles were patent. The right lung resembled the left. The trachea was patent and the mucosa was normal. The hilar lymph nodes were small, soft, and discrete. Culture of material from the congested lung surfaces yielded gram-negative rods of the coliform group.

The left adrenal measured 2 by 2.5 by 0.2 centimeters. On section, the cortex was bright yellow and thin. The medulla was scanty. The right adrenal gland measured 3 by 1.5 by 0.5 centimeters and resembled the left.

FIG. 1

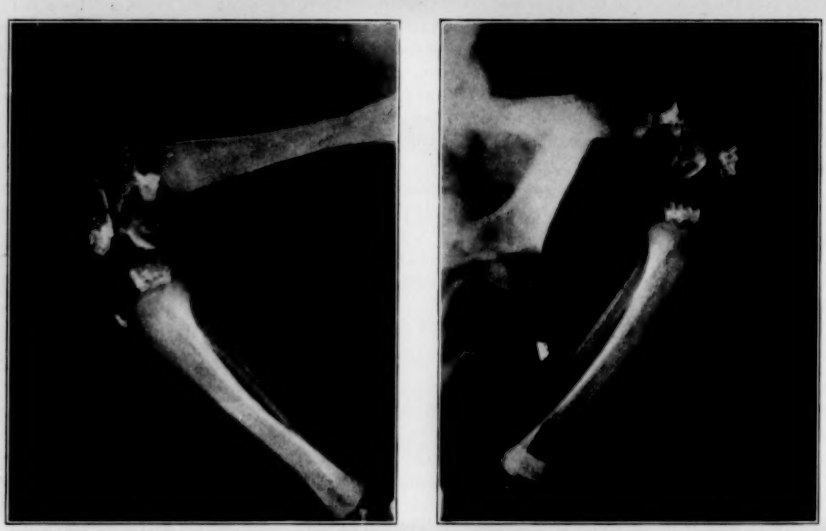

FIG. 2

The anterior fontanelle was 7 centimeters long and 5.5 centimeters wide. The posterior fontanelle was closed. The bones were firm, but cut easily with gritty resistance. The falx cerebri and the tentorium cerebelli were normal. There was no evidence of injury to the skull. The posterior clinoid processes of the sella turcica were sharply angulated forward and almost overrode the anterior clinoid processes, being separated from them by an interval of 0.1 to 0.2 centimeter. The pituitary gland measured 0.8 by 0.3 by 0.2 centimeter.

The lumbar vertebrae, pelvis, and a short section of the proximal portions of the femora were removed for examination. There was moderate fixation of the femora, and mobility was restricted to an estimated 50 per cent. of normal. On section, the head and neck of the right femur, as well as the acetabulum, appeared normal. The periarticular tissues appeared denser than normal and were fibrotic. Adjacent muscles were normal. Cross section of all lumbar vertebrae revealed nothing of note. Other findings were normal.

The anatomical diagnoses were: (1) chondrodystrophy calcificans congenita (x-ray diagnosis); (2) contracture of all extremities; (3) cleft palate; and (4) acute congestion of both lungs.

Microscopic examination of the lungs showed intense congestion of the capillaries. In some areas there was intra-alveolar hemorrhage. Increased deposition of blood pigment was present in the spleen.

Section through the right hip joint showed extensive pathological changes. The joint space was filled with dense vascularized connective tissue, containing areas of bone formation. Villous-like tags of fibrofatty tissue were attached to the synovial surfaces. These structures were rich in small blood vessels. The articular hyaline cartilages were thickened, but were not otherwise remarkable. There was scarcely any epiphyseal line, as the cancellous bone and cartilage joined abruptly,—apparently diaphyseal aclasis. In some parts of the thickened synovial membrane were considerable amounts of amorphous granular material, mingled with indefinable bony and calcific particles, some of which resembled poorly developed bone. A few foreign-body giant cells were present. At one point, this material formed an appreciable mass in the synovial membrane. In the cancellous bone, the trabeculae were few, quite narrow, and tended to be obscured by the hyperplastic marrow, in which the usual variety of marrow cells were present, but megakaryocytes were fairly abundant. The muscle fibers surrounding the bone appeared atrophic and showed an occasional focus of hyaline-cartilage formation, surrounded by connective tissue and inflammatory cells. The portion of the acetabulum adjacent to the femoral head consisted of fibroblasts, within which were various-sized foci of blue-staining homogeneous material resembling cartilage, among the muscle bundles of the voluntary muscles surrounding the hip joint. These foci were surrounded by numerous small and large mononuclear cells and immature cells of the granular series. Cartilage and bone formation was present within proliferating connective tissue in the joint space.

The microscopic diagnosis was chondrodystrophy calcificans congenita.

DISCUSSION

1. In addition to the presence of stippled, greatly enlarged epiphyses, the femora (Figs. 1, 2, and 3) and humeri were abnormally short and wide. This would suggest a definite relationship between this disease entity and the more common types of achondroplasia and chondrodystrophy. It seems probable that, had this child reached maturity, she would have shown some characteristics of dwarfism, even though the stippled epiphyses might have fused normally, as in the cases followed by Raap.

2. The presence of associated congenital defects in a majority of the cases reported is of considerable interest. The work of Gregg and others suggests that a careful history should be obtained regarding the presence of exanthemata during the early months of pregnancy, although no such history could be obtained in this case.

3. A familial tendency is certainly suggested by a review of the cases in the litera-

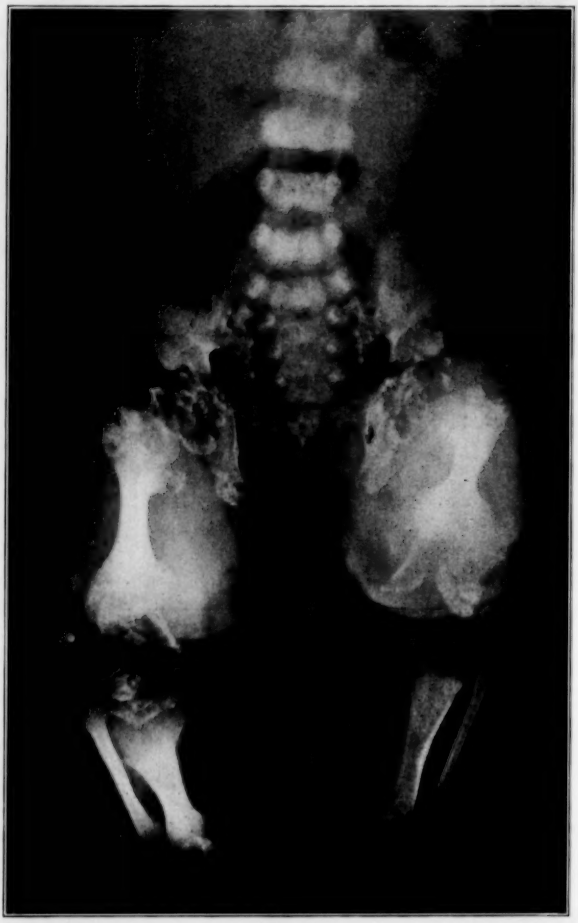

FIG. 3

ture. The case reported here was a first-born child of a nineteen-year-old father and a seventeen-year-old mother. This woman has since delivered a second full-term child, who presented no abnormalities, either clinically or by roentgenogram.

4. Laboratory studies in the authors' case were of little significance, except for a slightly elevated alkaline phosphatase. In the case of Borovsky and Arendt, an abnormally high phosphatase was found. We have been unable to find other reports citing such a marked deviation from normal.

5. The diagnosis rests on the roentgenographic findings. It is of significance, however, that flexion deformities of the extremities have been present in a number of cases. Perhaps this phenomenon, associated with other congenital defects, should suggest the possibility of this disease entity. Routine neonatal films on such patients might reveal a higher incidence than has previously been suspected. This is somewhat confirmed by Raap's statement that the stippling disappears by the age of three.

6. The microscopic sections of the involved areas again suggest that this condition is closely allied to the general group of achondroplasia and chondrodystrophy.

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A SIMPLIFIED DRILL FOR THE BANKART OPERATION

BY KARL S. ALFRED, M.D., CLEVELAND, OHIO

From the Division of Orthopaedic Surgery, University Hospitals, Cleveland

The Bankart operation has proved to be a highly efficient procedure in the repair of recurrent dislocation of the shoulder. However, it is a technically difficult procedure because of the inconvenience of the depth of the wound and the approach to the rim of the glenoid.

After the glenoid has been exposed, the next step is the placing of drill holes through the rim; this has proved to be the most difficult part of the procedure. Various means had been tried, including awls, curved guides for Kirschner wire, the right-angle dental drill, and other methods which seemed feasible. Of these, the dental drill was the most efficient, but also had several disadvantages: Maintaining asepsis is cumbersome and more assistance is needed to do so; the slightest amount of extra pressure will stop a dental drill from turning; moreover, this drill is not available in most hospitals.

In a constant search for an instrument to simplify the operation, the author was impressed favorably by a right-angle burr used in the perforation of a maxillary antrum. Examination of the instrument revealed it to be easily adaptable to a drill.

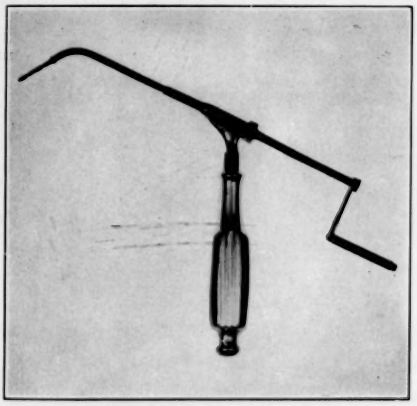

FIG. 1

The instrument assembled and ready for use.

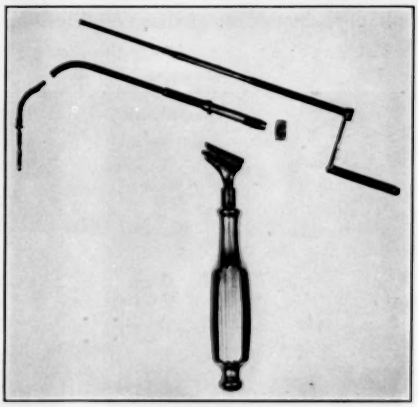

FIG. 2

The disassembled instrument.

The burr was removed and a steel drill point, five-eighths of an inch long, of three thirty-seconds gauge, was attached to the chain drive. Figures 1 and 2 illustrate the instrument ready to be used and disassembled. The length of the drill is more than adequate for drilling through the rim of the glenoid.

The performance of the instrument simplified the operation considerably. The usual exposure was more than adequate for placing the drill point in the proper position. The angle of the drill was perfect in relation to the rim of the glenoid and only a few turns of the drive shaft were necessary to drill through the rim.

Substitution of a perforator point for the drill point has made the instrument even more efficient.

The time for the procedure has been shortened considerably by the use of this drill or trephine. It is recommended to those who have had the same difficulty in performing this operation.

INTERNAL PROSTHESIS FOR UPPER PORTION OF FEMUR

A Case Report

BY LYON K. LOOMIS, M.D., NEW ORLEANS, LOUISIANA

From the Department of Orthopaedics, Louisiana State University School of Medicine, New Orleans

In 1943, Moore and Bohlman [1] reported a case in which a Vitallium model was substituted for the upper portion of the femur, which had been resected because of a large giant-cell tumor. The appliance was inserted in September 1940 and remained in place until the patient's death, from a cardiac attack, on June 2, 1942.

This paper is the report of a similar substitution for loss of bone substance due to shotgun wound. Considerable scar tissue was present in the region where the appliance was to be inserted, and it was impossible to use a model similar to the one constructed by Moore and Bohlman, because it could not be covered with soft tissue on the lateral aspect of the hip. Therefore, a prosthesis (Fig. 1) was constructed with a straight neck; no attempts were made to anchor the short muscles immediately about the hip into the appliance, since most of these muscles had been destroyed by the injury.

E. C., a negro male, aged forty-three and weighing 135 pounds, received a close-range shotgun wound

FIG. 1

Photograph of prosthesis.

FIG. 2

Preoperative roentgenogram of hip.

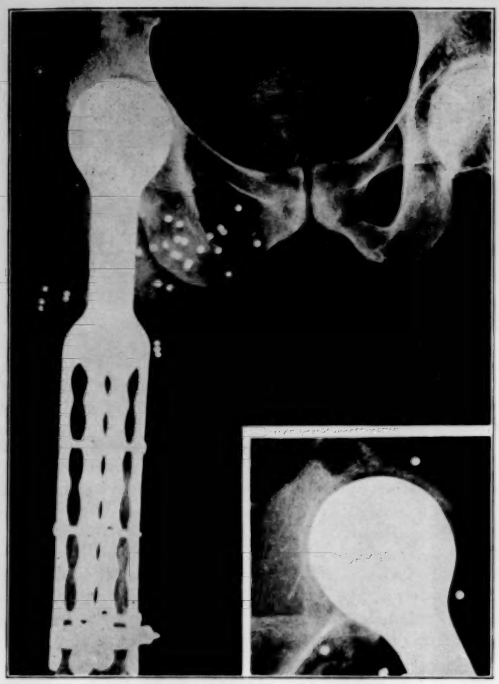

FIG. 3-A

FIG. 3-B

FIG. 3-C

Figs. 3-A and 3-B: Anteroposterior and lateral roentgenograms, three and one-half years following insertion.

Fig. 3-C: Photograph of patient, three and one-half years after operation.

to the right buttock in January 1944. The upper fourth of the femur, including the head, neck, and intertrochanteric region, was destroyed and subsequent low-grade infection resulted (Fig. 2). The wound healed about six months after the injury.

A review of the past history showed that the patient had fallen from a bicycle at twenty-six years of age, resulting in ankylosis of the right knee at 170 degrees of extension.

The prosthesis was inserted in February 1946. During the two-year period since the injury, about two inches of shortening of the right lower extremity had occurred, despite attempts to maintain length by traction. A lateral incision was made, extending from the mid-iliac crest to the supracondylar region. Particular attention was given to the fitting of the appliance to the femoral stump. The acetabulum was deepened superiorly so that, when traction was applied to the extremity, the head of the prosthesis could be reduced and would remain stable in the acetabulum. Before the wound was closed, the hip was noted to be stable in adduction, abduction, and flexion. However, it was possible to flex the hip only from 180 degrees

FIG. 4-A

FIG. 4-B

FIG. 4-C

FIG. 4-D

Patient has a complete range of internal and external rotation. Other motions are about 30 per cent. of normal.

to 135 degrees, due to the old ankylosis of the right knee and hamstring tightness. The patient withstood the procedure well, having received 1,000 cubic centimeters of whole blood during the operation. The postoperative course was uncomplicated and the wound healed by primary intention.

The hip was immobilized for six weeks following operation by a one and one-half hip spica. When the cast had been removed, active and passive exercises were instituted in bed with the limb suspended in a hinged Thomas splint. Six months after operation the patient started walking with an ischial weight-bearing brace. Ten months after operation he began gradually increasing weight-bearing without the brace, controlled increase in weight being applied by having the patient step upon a bathroom scale.

During the four years since the operation (Figs. 3-A, 3-B, and 3-C), the patient has been seen at three-month intervals. He rides a distance of 120 miles alone on a bus and, in reaching the office, makes his way unassisted through heavy city traffic. He works at his regular occupation as a yardman. There is a normal range of internal and external rotation; other motions in the right hip are about 30 per cent. of normal (Figs. 4-A to 4-D). The patient does not complain of pain with hip motion or weight-bearing.

1. MOORE, A. T., and BOHLMAN, H. R.: Metal Hip Joint. A Case Report. J. Bone and Joint Surg. **25**: 688–692, July 1943.

CONGENITAL ABSENCE OF THE ODONTOID PROCESS

REPORT OF A CASE

BY DANIEL M. STIEFEL, M.D., DETROIT, MICHIGAN

This case of congenital absence of the odontoid process of the axis is presented because of the rarity of such reports in the literature [1, 2, 3]. It was also considered interesting by the author because of the marked excursion of the atlas upon the axis, which could be demonstrated by manipulation and by roentgenogram.

The patient, a woman, twenty-four years old, complained of pain in the proximal portion of the neck posteriorly. Routine examination of the mobility of the cervical spine disclosed unusual excursion of the head during passive motion.

FIG. 1

Atlanto-axial region, showing absence of the odontoid process.

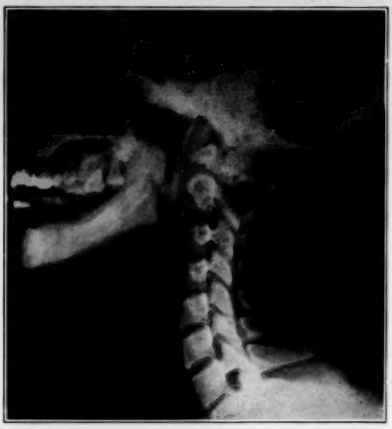

FIG. 2

Roentgenogram showing that atlas is displaced somewhat posteriorly on the axis.

FIG. 3

Head was pushed backward during roentgenographic exposure.

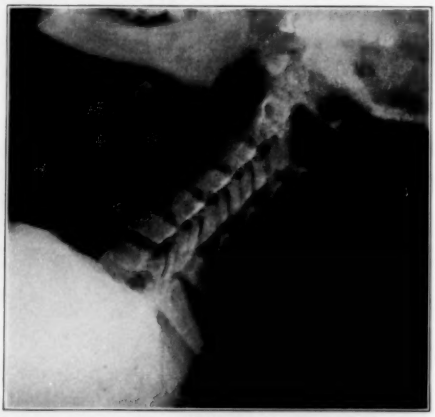

FIG. 4

Head was pushed forward during roentgenographic exposure.

Roentgenograms showed absence of the odontoid process of the axis (Fig. 1); further roentgenographic examinations were then made. In Figure 2, the relationship of the first two cervical vertebrae is shown under static conditions. The atlas is displaced somewhat posteriorly on the axis. An additional view was obtained by pushing the head forward and holding it in this position during the roentgenographic exposure. A marked degree of excursion was shown (Fig. 4). Another view was obtained by pushing the head backward during the exposure (Fig. 3).

The dangers attendant on such instability were explained to the patient and her relatives. A stabilizing procedure was advised, consisting of operative fusion of the first two cervical vertebrae. However, the patient has not consented to operative treatment.

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1. ROBERTS, S. M.: Congenital Absence of the Odontoid Process Resulting in Dislocation of the Atlas on the Axis. J. Bone and Joint Surg., **15**: 988–989, Oct. 1933.
2. SCANNELL, R. C.: Congenital Absence of the Odontoid Process. A Case Report. J. Bone and Joint Surg., **27**: 714–715, Oct. 1945.
3. WEILER, H. G.: Congenital Absence of Odontoid Process of the Axis with the Atlanto-Axial Dislocation. J. Bone and Joint Surg., **24**: 161–165, Jan. 1942.

A TABLE ATTACHMENT FOR THE ELECTRIC SAW

BY MOSES RABSON, M.D., NEW YORK, N. Y.

From the Hospital for Special Surgery, New York City

A device is presented to make the use of the electric saw safer. When free bone grafts are needed, an assistant cuts them to the required size and shape. Under usual conditions, he holds the saw with one hand and the graft with the other. This procedure is complicated by the fact that the teeth of the saw may catch suddenly, upsetting the equilibrium the man has been trying to maintain. At that moment, the whirling blade is a dangerous and uncontrollable menace. Deep cuts, including nerve, tendon, and bone of the fingers, are possible, or the graft may be thrown to the floor.

By the addition of a combination table and bench, the Luck saw, or any other saw including the Stryker, can be used by one man to cut a graft of any size or shape. The present device was developed by the author. It has been used at the Hospital for Special Surgery for the last six months, and has given complete satisfaction.

The device illustrated converts the free saw into a bench saw with a table that can be adjusted for any depth of cut. This table was made of stainless steel; it was constructed in the brace shop by means of simple tools. The base plate should be made of heavy steel. If the metal is too light, the base will tend to bend as a result of use and the blade will not fit into the slot. In addition, the added weight helps to prevent creeping of the saw.

In making this attachment, it is important to get the slot on the table at the correct distance from the guard around the electrical connection on the saw. If this guard fits snugly into the uprights (Fig. 1), the blade will remain in the proper position in the table.

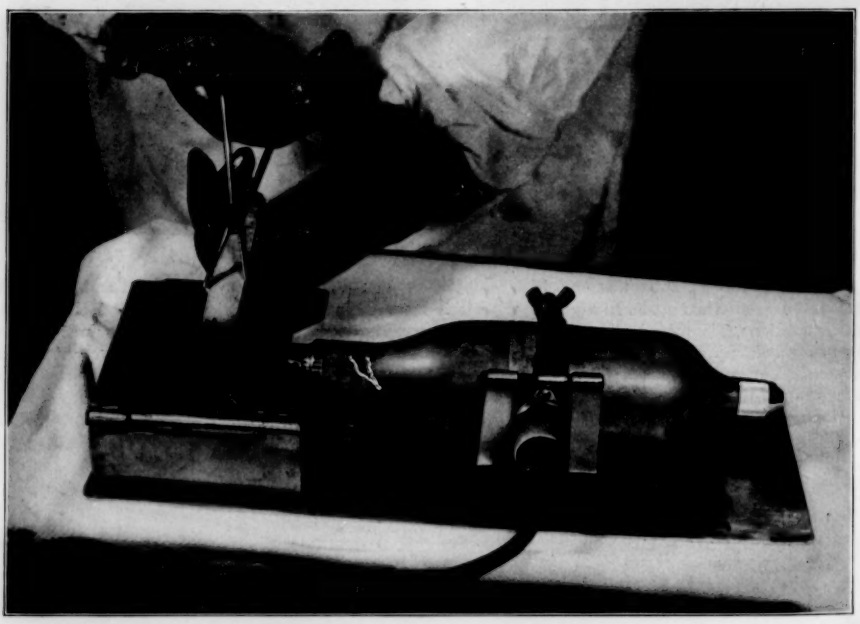

FIG. 1

Back view, showing saw in use. Note the snug fit of the guard and the uprights.

The top strap locks the saw in place (Figs. 2 and 3), so that the motor will not move in relation to the table. Markings, one-quarter inch apart, are scribed on the table to assist in measuring the width of the graft to be cut. The unit can be assembled or taken apart in one minute.

When in use, the blade rotates toward the operator so that, if the bone is caught by the blade, it will be forced against the top of the table and will not be lost.

The bone can be held easily with either a uterine tenaculum or a large Kocher clamp. The large pieces can be held safely by hand, if desired. With a little practice, slivers, one-sixteenth of an inch by one-eighth of an inch by six inches in size, may easily be cut from tibial bone. Grafts in the shape of an H and other shapes may be cut, since the operator has both hands free to hold the graft and move it.

When bone from a bank is used, there will be greater need for this device, since almost every piece of bone used has to be cut to a specific size and shape.

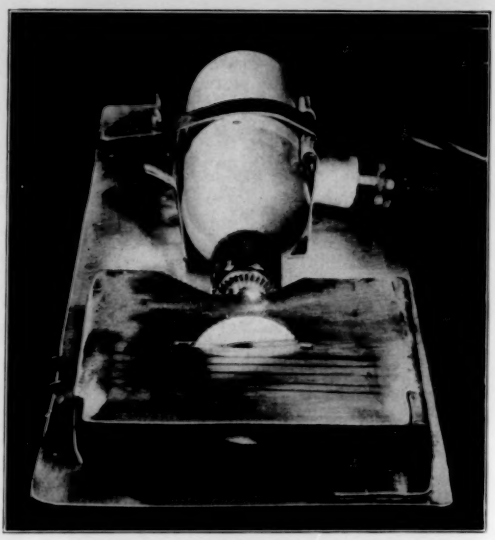

FIG. 2
End view.

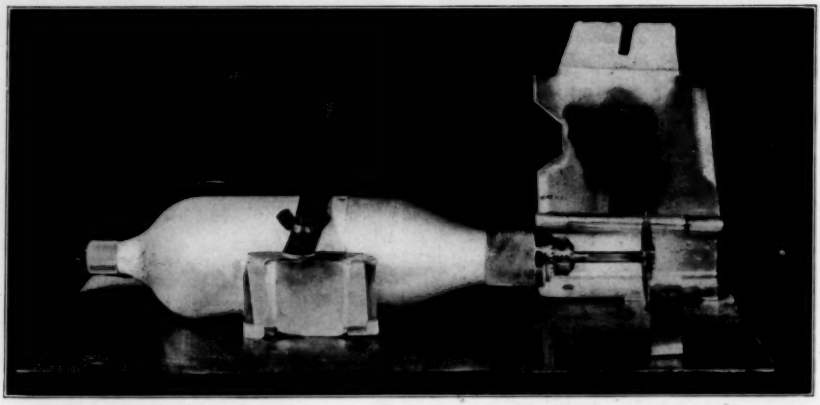

FIG. 3

Front view with the table part lifted. By tightening the wing nut in various places on the slot, the depth of cut can be adjusted.

SIMPLE ADAPTER FOR MOUNTING HEAD OF X-RAY TUBE TO FRACTURE TABLE *

BY MORTON H. LEONARD, M.D., LOUIS W. BRECK, M.D., W. COMPERE BASOM, M.D., AND HERBERT S. LOSEFF, M.D., EL PASO, TEXAS

Success in the closed nailing of fracture of the femoral neck depends greatly upon obtaining diagnostic anteroposterior and lateral roentgenograms quickly, without displacement of the fragments or contamination of the wound. An adapter for mounting the head of a portable x-ray tube to the fracture table, so that the tube head can be moved

FIG. 1-A

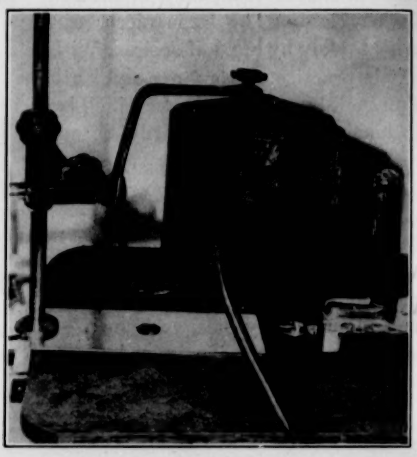

FIG. 1-C

Fig. 1-A: The bushing is inserted into the hole commonly used to receive table upright.

Fig. 1-C: Close-up of tube in place. Mobility is obtained by the intrinsic adjustments of tube stand, or by lowering or raising table top.

FIG. 1-B

The upright is inserted into bushing. Wing bolts pass through bushing and, by pressure on flat surface of rod, control rotation.

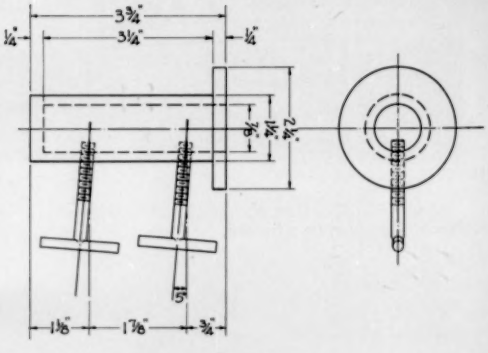

FIG. 2

Reproduction of blueprint.

* Presented as an exhibit at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 11 to 16, 1950.

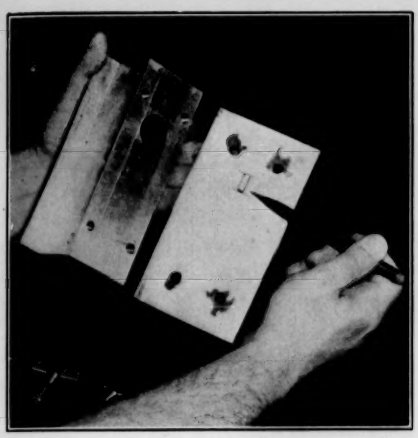

FIG. 3-A

FIG. 3-B

Fig. 3-A: Adapter opened. The flange on the bottom plate fits into slot on end of tube upright and controls rotation.
Fig. 3-B: Adapter is inserted between lower bars of table.

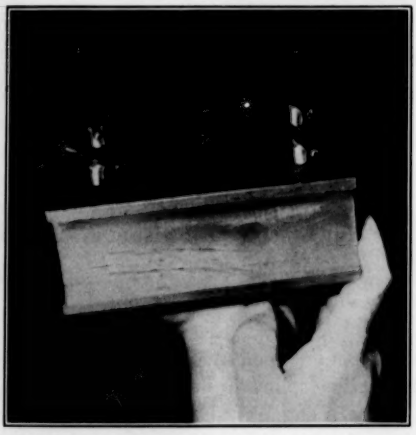

FIG. 3-C

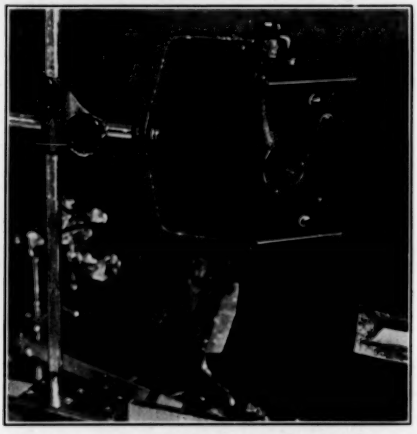

FIG. 3-D

Fig. 3-C: The device is clamped in position by the bottom plate.
Fig. 3-D: Detail of tube in position.

in three directions, has been found by the authors to be a successful and facile way of getting good lateral roentgenograms during hip pinning.

A brass adapter cylinder has been designed to receive the upright of one of the commercial shock-proof tube heads. This bushing is placed in the hole at the foot of the table ordinarily employed to install the table upright (Fig. 1-A). The cylinder and its use with one of the commonly employed tables are illustrated (Figs. 1-B and 1-C). Figure 2 indicates the details of construction.

For another commonly employed table, a box-like contrivance is clamped on the lower parallel bars. It carries a socket to receive the upright of the tube. This device is shown in Figures 3-A to 3-D and its plan in Figure 4.

These devices permit mounting the head of the x-ray tube, with mobility in all planes, to either type of table. This three-directional movement is of particular advantage in the

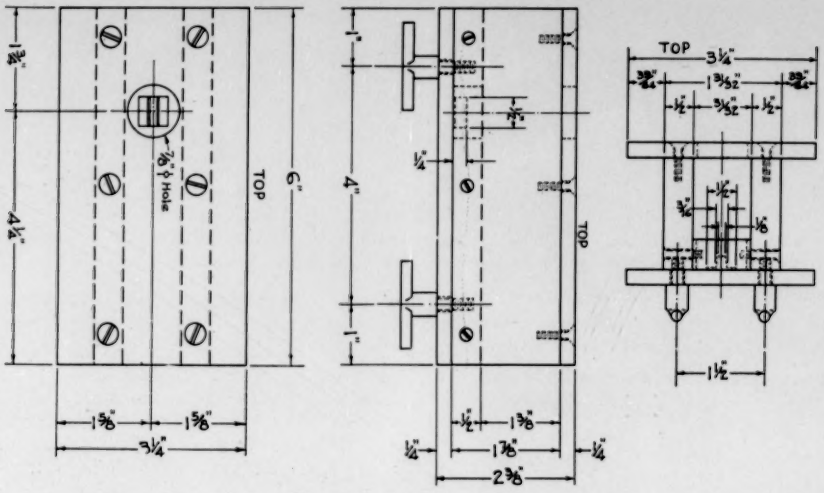

FIG. 4

Reproduction of blueprint of adapter box.

parasagittal plane. Such flexibility is not possible when the tube head is fixed on a sacral rest. An adapter similar in principle can easily be made for other fracture tables.

BAMBOO STAFF FOR DELTOID PARALYSIS

BY WILLIAM BEECHER SCOVILLE, M.D., HARTFORD, CONNECTICUT

From the Department of Neurosurgery, Hartford Hospital

FIG. 1

A bamboo staff has been used to replace the more cumbersome airplane splint for maintaining elevation of the arm in cases of paralysis of the deltoid. The device consists of a bamboo pole which may be obtained from any rug shop, or an old-fashioned long ski pole.

A rubber end, like that used on crutches, is attached to the bottom of the pole; and on the top is fastened a small cross piece and a soft leather thong, looped for attachment to the wrist.

When the patient walks, the pole is pushed with the contralateral arm.

This staff has proved of value, especially for use indoors, in those patients not having extensive brachial plexus paralysis. Two patients have registered sufficient enthusiasm to justify publication of this brief report.

Fig. 1

Pole support for patient with deltoid paralysis following fracture-dislocation of the fifth on the fourth cervical vertebra.

THE USE OF OVERSHOE BUCKLES IN BRACES

BY HERMAN L. RUDOLPH, M.D., READING, PENNSYLVANIA

The traditional use of laces or straps and buckles on the cuffs of lower-extremity braces presents a difficult problem for those who have some disability of the hands. For example, the hemiplegic with total disability of one upper extremity and a brace on the lower extremity would need assistance if supplied with laced cuffs. The use of a strap and buckle has been found much more satisfactory in a self-care training program, but this, too, requires dexterity of the one good hand for the application and removal of a brace.

The overshoe buckle has simplified the use of the shoe and brace for one of the author's hemiplegics, and has made the patient entirely independent of assistance. This buckle requires very little dexterity, so that conceivably it might be used by patients with poliomyelitis or cerebral palsy, who have minor disabilities of the hands. This buckle permits of minor adjustments for varying circumference of the parts, and can be cinched easily for a snug fit. Finding stores do not stock this item, since there are no calls for replacement on overshoes; this attests to its durability. These buckles are easily attached by a brace-maker.

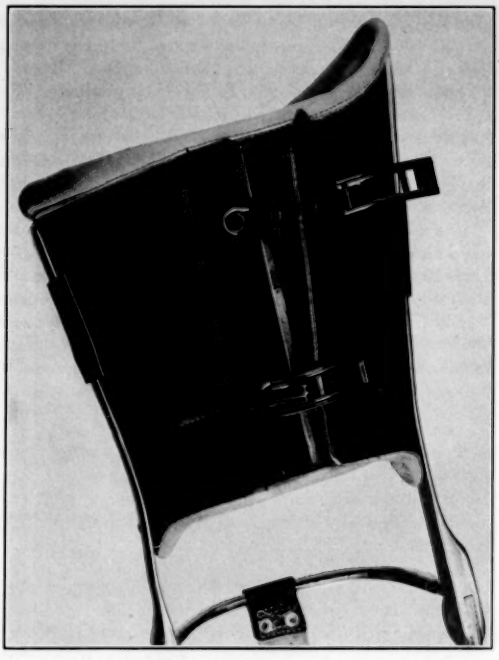

FIG. 1

A search of the available literature has failed to reveal a description of this simple modification of a cuff fastener. It is presented now with the belief that the handling of a brace can be a simple, time-saving, and independent manoeuvre for the physically handicapped.

CORRECTION

Dr. Walter P. Blount has called attention to an error in the article by Dr. George R. Clarke and himself, entitled "Control of Bone Growth by Epiphyseal Stapling. A Preliminary Report", which was published in *The Journal* for July 1949, Volume 31-A, pages 467 and 468. The paragraph starting at the bottom of page 467 should read:

"Exposure of the lateral aspect of the distal femoral epiphysis is only slightly more difficult. It is a mistake to incise the fascia lata with the knee extended. With the knee flexed, the thin *anterior* expansion of this fascial layer may be split longitudinally, just *anterior* to the iliotibial tract, which is then retracted posteriorly. The vastus lateralis is displaced anteriorly without division of any of its fibers. The mobile soft parts may be retracted easily to expose the condyle, either anteriorly or posteriorly."

VERNON L. HART

1898–1950

Dr. Vernon L. Hart, known by all his friends as "Bill", was drowned while swimming in a lake near his home in Minneapolis on July 12. With his death the orthopaedic profession lost one of its most active and creative minds. At many meetings of The American Academy of Orthopaedic Surgeons and of the American Medical Association, Dr. Hart's exhibits created great interest, and his enthusiasm on these occasions will long be remembered by those who followed his work, which was always stimulating to his colleagues.

His work on dysplasia of the hip joint was a definite major contribution to the subject of congenital dislocation of the hip, and was outstanding in its thoroughness. At the time of his death, he had just finished a book which will soon be published under the title of *Congenital Dysplasia of the Hip*.

Dr. Hart was fifty-one years of age at the time of his death. He was born in Huron, Ohio, on October 2, 1898. His medical education was obtained at the University of Michigan, from which he received his degree of Doctor of Medicine in 1924. Following his graduation, he spent eight years at the University of Michigan as intern, resident, fellow, postgraduate instructor, and then as head of the Department of Orthopaedic Surgery. After practising in Dayton, Ohio, for one year, he moved to Minneapolis in 1933 and took over the office of the late Dr. Emil Geist, who had died shortly before. He continued this practice and served on the faculty of the Medical School of the University of Minnesota until his death, except for an absence during his military service.

As a Lieutenant Colonel during World War II, Dr. Hart was consultant to the Seventh Service Command and headed the Orthopaedic Service in several Army Hospitals. Later he was a member of the National Research Council. In 1948, he was a civilian consultant to the Surgeon General of the United States Army on an inspection tour of the hospitals in the American Zone of Germany.

Dr. Hart was a diplomate of The American Board of Orthopaedic Surgery, a fellow of The American Academy of Orthopaedic Surgeons, and a member of the Clinical Orthopaedic Society, in addition to several other local and national societies. He will be greatly missed by his friends and associates.

ROBERT BARKER COFIELD

1877–1950

On July 14, 1950, Dr. Robert Cofield died at Christ Hospital in Cincinnati. Until the past several years, he was a most active orthopaedic surgeon in Cincinnati.

Dr. Cofield was born December 31, 1877, in Richmond, Indiana. In 1903, he was graduated from the College of Medicine of the University of Cincinnati. From 1906 until 1918, he was associated in the practice of orthopaedic surgery with Dr. Albert H. Freiberg. In 1918, he opened his own office and, in the same year, organized the Orthopaedic Service at Christ Hospital in Cincinnati, of which he remained in charge until a few years ago.

Dr. Cofield was an able orthopaedic surgeon; he was conservative in his therapy, though accepting newer operative procedures when they had been duly proved. He had been a member of The American Orthopaedic Association since 1925. Although he was one who rarely discussed papers at the meetings of the Association, his infrequent discussions were characterized by brief comments to the point at issue and were of real value.

Dr. Cofield was a member of the Medical Advisory Committee of the Cincinnati Chapter of The National Foundation for Infantile Paralysis, Consulting Orthopaedic Surgeon at the Cincinnati Children's Hospital, past Director of the Orthopaedic Service and past President of the Staff of the Cincinnati Christ Hospital.

In Dr. Robert B. Cofield's passing, The American Orthopaedic Association has lost a loyal friend, and Cincinnati has lost one of its most respected citizens.

News Notes

The Annual Meeting of **The British Orthopaedic Association** will be held in London on October 26, 27, and 28, 1950.

The Eighteenth Annual Meeting of **The American Academy of Orthopaedic Surgeons** will be held under the presidency of Dr. Guy A. Caldwell at the Palmer House, Chicago, January 27 to February 1, 1951.

The Sixth Annual Meeting of the **American Society for Surgery of the Hand** will be held at the Palmer House, Chicago, on Friday, January 26, 1951. All members of The American Academy of Orthopaedic Surgeons and their guests will be welcome. There will be a nominal registration fee.

The Seventy-eighth Annual Meeting of the **American Public Health Association** will be held in Kiel Auditorium, St. Louis, Missouri, October 30 to November 3. Meetings of related groups will take place concurrently. Additional information may be obtained from Dr. Reginald M. Atwater, Executive Secretary, 1790 Broadway, New York, N. Y.

The Annual Meeting of the **American Academy for Cerebral Palsy** will be held at the Palmer House, Chicago, on Friday and Saturday, October 20 and 21. The Friday afternoon session will be open to visiting orthopaedic surgeons and any physicians interested in the problem of cerebral palsy.

Dr. Harold A. Sofield, Secretary of **The American Board of Orthopaedic Surgery, Inc.,** announces that December 31, 1950, is the deadline for receipt of applications for Part I examinations for 1951.

The **Kappa Delta Award for Research in Orthopaedic Surgery,** a prize of one thousand dollars, donated by the Kappa Delta Sorority, is awarded annually by **The American Academy of Orthopaedic Surgeons** for the best research done in orthopaedic surgery or a related scientific field by an individual in the United States. The second award, for the year 1950, will be presented at the Eighteenth Annual Convention of the Academy in Chicago, January 31, 1951. Researchers interested are requested to secure further information from Dr. R. Beverly Raney, Duke Hospital, Durham, North Carolina, Chairman of the Award Committee for 1950.

The Annual Convention of the **National Society for Crippled Children and Adults** will be held October 26, 27, and 28, 1950, at the Stevens Hotel, Chicago. Marking twenty-nine years of the Society's service for the handicapped, the Convention will feature prominent authorities working in the field of the disabled, who will present latest developments in the treatment, training, and care for the nation's handicapped children and adults.

The **Arthritis and Rheumatism Foundation** is offering fellowships for research in the basic sciences related to the study of arthritis. Applications should be sent to the Medical and Scientific Committee of The Arthritis and Rheumatism Foundation, 535 Fifth Avenue, New York 17, N. Y.

The next Congress of the **International Society of Orthopaedic and Traumatic Surgery** will be held in Stockholm, May 21–25, 1951. The Secretary of the Congress is Dr. Anders Karlen, Karolinska Institutets Ortopediska Klinic, Stockholm.

The two main subjects will be: (1) Avitaminosis and Bone Changes, with Dr. R. Zanoli of Italy and Dr. E. Rutishauser of Switzerland as the principal speakers; and (2) Low-Back Pain and Sciatica. Results of Treatment, with Dr. Joseph S. Barr, of Boston, Massachusetts, as the first speaker.

At the Central Office of **The American Academy of Orthopaedic Surgeons,** 122 South Michigan Avenue, Chicago, Illinois, there is being established a file of the names of interns needing resident training and of hospitals needing residents. Those interested should make application to the Central Office.

"A Manual of Cerebral Palsy Equipment", sponsored by **Zeta Tau Alpha,** has recently been published by the **National Society for Crippled Children and Adults.** This manual fills a real need and represents an important contribution.

The **Kessler Institute for Rehabilitation** has recently announced the publication of the second of its series of rehabilitation manuals, "The High Double Arm Amputee", written by John B. Seely, who is himself a double arm amputee, and consultant in amputee training in the Kessler Institute. This manual may be obtained from the Kessler Institute for Rehabilitation, Pleasant Valley Way, West Orange, New Jersey. Karl Arthur Maxwell, M.D., has recently been appointed Associate Medical Director of the Kessler Institute.

We are pleased to announce the formation of **Sociedad de Ortopedia y Traumatología del Uruguay**. The following are the present officers: *President*, Dr. José Luís Bado; *Vice-President*, Dr. D. Vazquez Rolfi; *Secretary*, Dr. Herbert Cagnoli; *Treasurer*, Dr. José Suarez Meléndez; and *Official*, Dr. Francisco Paternó.

Following his retirement from the chair of orthopaedic surgery at the State University of Iowa, Dr. Arthur Steindler, now Professor Emeritus, has continued in the practice of orthopaedic surgery at Mercy Hospital, Iowa City, where he is in charge of the Orthopaedic Department. Here he will conduct his famous seminars on orthopaedic subjects, the proceedings of which will be issued in mimeograph form as "Proceedings and Seminar Notes of the Orthopaedic Department of Mercy Hospital". It is planned to issue the first volume in two sections; one has recently appeared and one is scheduled to appear in April of 1951.

Dr. Steindler is succeeded as Professor of Orthopaedic Surgery at the University of Iowa by Dr. Carroll B. Larson who, in assuming his new responsibilities in August, returned to his alma mater and native state after many years of training, clinical investigation, teaching, and practice in Boston, where he has a host of friends and well-wishers.

A two-week **Institute in Cerebral Palsy**, for qualified physicians, nurses, physical, occupational and speech therapists, social service and guidance workers, and teachers, will be held in New York City, beginning Monday, November 6, under the auspices of **The Coordinating Council for Cerebral Palsy.** An eminent faculty of physicians and professional personnel, authorities in their individual fields, will participate in the program of lectures, clinical demonstrations, and seminars.

Following the Institute, opportunities for a three-month in-service training course will be available to a limited number of physicians and therapists.

Further information can be obtained from Miss Marguerite Abbott, Executive Director of the Council, 270 Park Avenue, New York 17, N. Y.

Readers of *The Journal* who have had dealings with V. Mueller and Company will regret that George W. Wallerich, President of the Company, died on July 3. Mr. Wallerich was known best for his interest in the development of surgical instruments. His advice was frequently sought by surgeons desiring improvements in older types of surgical instruments, and by those who required new instruments for new procedures and modifications in technique. They recognized his ability and his long experience in the surgical-instrument field.

The First Congress of **Sociedad Latino-Americana de Ortopedia y Traumatología** will take place December 8 to 17, 1950, at Montevideo (Uruguay), Buenos Aires (Argentina), and Mar du Plata, the exclusive summer resort near both cities. Dr. Alberto Inclán, of Havana, is President of this Congress. He personally and Dr. Juan Farill, President of the Society, extend a most cordial invitation to members of The American Orthopaedic Association and the Canadian Orthopaedic Association to attend this First Congress. The preliminary program for the Congress was published in the July *Journal*, page 707.

The address of the General Secretary of the Society is Dr. José Luís Bado, Institute de Traumatología, Montevideo, Uruguay.

RESEARCH COMMITTEE OF THE AMERICAN ORTHOPAEDIC ASSOCIATION

Is spine fusion necessary, or desirable, following the removal of a herniated disc? The differences in the opinions expressed by the various orthopaedic surgeons and neurosurgeons indicate the need for more information on this subject.

The American Orthopaedic Association, through its Research Committee, is attempting to find the answer by conducting a survey of the end results in patients treated with and without fusion, after removal of discs. The Veterans Administration has also been interested in this problem and has agreed to finance this survey. The information is to be based on a study of 1000 patients, five years or more after operation. Statisticians have been consulted with regard to the value of our sample, and a Fellow, Dr. James E. Simpson, has been selected to conduct the examinations. He will visit a number of clinics for this purpose.

Many clinics have already volunteered to make their records and their patients available for this study. It is hoped that other medical units having case material which can be of assistance in this project will write to the Chairman of the Committee, indicating the availabiltiy of their material. The Chairman is Dr. I. William Nachlas, 1109 North Calvert Street, Baltimore 2, Maryland.

Dr. K. E. Kallio has recently been appointed Professor of Surgery at the University of Helsinki, and Chief of the Third Surgical University Clinic. After devoting nearly ten years to practice and research in general surgery, he became interested in orthopaedic surgery and worked with Professor Langenskiöld in the Orthopaedic Hospital of the Invalid Foundation, a large hospital for the treatment of trauma and for rehabilitation. He has had opportunity for study in various countries. Professor Kallio is the first orthopaedic surgeon in Finland to be honored with an appointment as chief of a university clinic.

THE ASSOCIATION OF MILITARY SURGEONS OF THE UNITED STATES

The Association of Military Surgeons of the United States will hold its 1950 convention at the Hotel Statler, New York City, from Thursday, November 9, to Saturday, November 11. The following program has been planned:

THURSDAY, NOVEMBER 9

Afternoon Session

Civil Defense Planning.
Norvin C. Kiefer, M.D., Director, Health Resources Division, National Security Resources Board.
The World Medical Association.
Louis H. Bauer, M.D., F.A.C.P., Secretary General of the World Medical Association; Chairman, Board of Trustees, American Medical Association.
Total Rehabilitation in Total Mobilization.
Howard A. Rusk, M.D., Professor and Chairman of the Department of Physical Medicine and Rehabilitation, New York University-Bellevue Medical Center.
Chemistry in the Detection of Crime.
Alexander O. Gettler, Ph.D., Professor of Toxicology, Medical College of New York University.

FRIDAY, NOVEMBER 10

Morning Session

Practical Considerations of a Blood Program in a National Emergency.
Lloyd R. Newhouser, Captain, Medical Corps, United States Navy.
Doctors and Defense.
James C. Sargent, M.D., Chairman, Council on National Emergency Medical Service, American Medical Association.
The Use of Anticoagulants in Military Medicine.
Irving S. Wright, M.D., Professor of Clinical Medicine, Cornell University Medical College.
The Selection of Antibiotics for Medical and Surgical Patients.
Chester S. Keefer, M.D., Professor of Medicine, Boston University School of Medicine.
Optimism in the Treatment and Prognosis of Cardiovascular Disease.
William D. Stroud, M.D., Professor of Cardiology, University of Pennsylvania Graduate School of Medicine.

Afternoon Session

Disease and Command Responsibility
Perrin H. Long, M.D., Professor of Preventive Medicine, The Johns Hopkins University School of Medicine.
A Supplementary Report on Dramamine.
Leslie N. Gay, M.D., Associate Professor of Medicine, The Johns Hopkins University School of Medicine.
The Surgery of World War III.
William F. Macfee, M.D., Surgical Director, St. Luke's Hospital, New York.
An Analysis of the Cold War.
Paul Linebarger, Ph.D., Professor of Asiatic Politics, School of Advanced International Studies, Washington, D. C.

SATURDAY, NOVEMBER 11

Morning Session

A Practical Solution to the Medical Reserve Training Program.
Harold W. Glattly, Colonel, Medical Corps, United States Army.
Reserve Activities of the Medical Services of the Department of Defense.
Richard L. Meiling, M.D., Director of Medical Services, Department of Defense.
The Place of the Professional Consultant in the Reserve.
Frank B. Berry, M.D., Brigadier General, United States Army Reserve, Consultant to the Surgeon General and Professor of Clinical Surgery at Columbia University.
Reserve Legislation.
John P. Bracken, Commander, United States Navy Reserve, Immediate Past President, Reserve Officers Association.

Discussion on the preceding papers will be opened by Winchell McK. Craig, M.D., of the Mayo Clinic, Rear Admiral, United States Navy Reserve.

Book Reviews

BONE AND JOINT DISEASES. PATHOLOGY CORRELATED WITH ROENTGENOLOGICAL AND CLINICAL FEATURES. J. Vernon Luck, M.S. (Ortho.), M.D., F.A.C.S., F.I.C.S. Springfield, Illinois, Charles C. Thomas, 1950. $16.50.

In this complete and dependable textbook of applied pathology, Dr. Luck has succeeded admirably in correlating the pathological, roentgenographic, and clinical features of bone and joint diseases. For just such a book the need has been long and urgent.

Designed primarily for the clinician, the clinical pathologist, and the roentgenologist, the descriptions have been limited to the accredited body of knowledge of these features of the diseases discussed. In so far as present-day knowledge permits, the pathological changes have been presented as aberrations from physiological processes.

The author has carefully avoided the pitfalls of unverified and controversial concepts, and seems to have resolutely resisted the temptation to be dogmatic or to pass judgment.

The clear and concise text is well illustrated by reproductions of photographs of carefully selected pathological material, gross and microscopic, well chosen roentgenograms, and photographs of typical patients.

The less commonly encountered bone and joint diseases have not been neglected, attesting to the magnitude of the author's experience and the extensive accumulation of pathological material to which he has had access. The chapters on bone and joint anatomy and physiology are excellent refreshers for the busy clinician.

This is a splendid volume which reflects great credit on both the author and the publisher. It is a book which all who are in any way professionally concerned with orthopaedic surgery will wish to own.

LEHRBUCH DER RÖNTGENDIAGNOSTIK. Band I: Skelett. H. R. Schinz, W. E. Baensch, E. Friedl, und E. Uehlinger. Stuttgart, Georg Thieme, 1950. (Distributed by Grune and Stratton, Inc., New York, N. Y.)

The first part of the fifth edition of this textbook of diagnostic roentgenology is now available in this country. Those familiar with the previous editions have eagerly awaited this announcement. Those who have had no earlier experience with this book can be assured that it will make an excellent addition to their libraries.

The present section deals with the theoretical features of diagnostic roentgenology, physics, protection, and general methods; one section is concerned with the diagnosis of the diseases of the skeleton with particular emphasis on the fracture problem. Many new paragraphs, chapters, x-ray reproductions, sketches, and diagrams have been added to the new edition.

The basic fundamentals and physical background of diagnostic roentgenography have been described briefly, but comprehensively, by J. Eggert, a collaborator, in language which is easily understandable even for one who has only limited knowledge of the physical factors involved in this rather complicated field.

A brief but important chapter is dedicated to the necessity for and the methods of protection against roentgen irradiation, electrical shock, fire, and other hazards. E. Brandenberger, another collaborator, has written about the medical application of x-ray crystallography.

General methods of the roentgenographic examination of the skeleton, the normal and pathological anatomy and physiology of bone, circulatory disturbances and bone damage through disuse, heat, cold, and electrical current are adequately and intelligently covered.

A large part of the book is devoted to the fracture problem. This chapter, written by G. A. Preiss, has been enlarged from approximately fifty pages to over two hundred pages in the present edition. The text is accompanied by numerous illustrations, some reproductions of roentgenograms, and some sketches and diagrams. There are chapters dealing with the mechanics and various types of fractures, their appearance on the roentgenograms, the physiology of healing, the various methods of treatment, and the complications,—all accompanied by many elaborate illustrations, making for a comprehensive and detailed study of this problem which, to the reviewer's knowledge, can hardly be found anywhere else.

No doubt unusual effort, great care, and expense have been expended to achieve the superior quality of the reproduction of x-ray films. These, together with the innumerable sketches and diagrams, contribute to make an otherwise dry subject stimulating and interesting. An extensive and useful bibliography, eliminated from the fourth edition, has been restored.

This book offers more to the reader than the usual textbook. It represents a *Handbuch* which is of interest not only to the roentgenologist, but also to all those whose work brings them in regular contact with the various problems involved in the diagnosis and treatment of the diseases and traumatic changes of bone.

It is to be hoped that a translation of this textbook into the English language will be made when all parts are available, a plan which had to be abandoned for the last edition at the outset of World War II.

Those who have a reading knowledge of the German language will find this book a valuable asset; those who do not know German still can enjoy a book which offers so much in text and illustrations.

SURGERY OF REPAIR. PRINCIPLES, PROBLEMS, PROCEDURES. (Two volumes.) John F. Pick, S.B., M.M., M.D., F.I.C.S. Philadelphia, J. B. Lippincott Company, 1949. $24.00.

This is the most extensive treatise on plastic surgery that we have seen. It is divided into three sections, dealing with "Principles", "Problems in Plastic Surgery", and "Procedures". It has been the intention of the author to deal with principles, methods, and procedures as developed by the expert plastic surgeon in such a way as to make them of use to all surgeons.

The history of plastic surgery from the crude methods used many years B.C. up to the present is well presented. It is pointed out that World War I was a milestone in the realization of the possibilities in this field. Between the two wars there was great development in all phases of plastic surgery, with wide use of the principles developed. As a result of the great development and teaching of surgery during this period, thousands of surgeons became trained in the methods and were able to use them in caring for the wounded of World War II. Credit is given to the surgeons who were the great teachers during this period.

Clever is the arrangement of material in the various chapters. For example, tissue aberrations are described as being either voids, derangements, or excesses. Voids are further subdivided into atrophies, aplasia, and tissue absence. Tissue derangements are classified as distortion, displacement, or misplacement. Various causes for derangement are outlined, the etiological factors being pressure, dystrophy, paralyses, tumors, and accidental trauma. "Tissue excess may be true or false, depending upon whether they are hypertrophies or hyperplasia, on the one hand, or neoplasms, misplacements or displacements, on the other." This same outline is used in the various chapters on regional problems.

The author emphasizes the psychological need of plastic repair in persons with congenital malformations, voids from accidents, hypertrophies, and deformities which make the patients unable or unwilling to mingle with their fellows.

One of the best chapters is that on skin grafts and grafting. In this is a chart showing the advantages and disadvantages of grafts of various thicknesses, the time consumed, possible complications, tissue cost, and the final results. The technique of cutting, placing, and dressing of grafts is described in great detail. The author describes and illustrates possible complications and indicates the best way to avoid them. There is a brief chapter on bone-grafting.

In the final section, procedures applicable to regions—that is, breasts, ears, extremities—are dealt with in great detail, according to the principles and procedures developed in the earlier chapters. Great stress is laid on the surgery of the extremities.

This is a valuable publication and represents the results of many years of study, experience, and teaching. The author is to be commended.

UNFALLORTHOPÄDIE. EINSCHLIESSLICH DER SPÄTBEHANDLUNG VON KRIEGSVERLETZUNGEN. Prof. Dr. Max Lange. Stuttgart, Ferdinand Enke, 1949.

As the result of World War II, Germany was left with the tremendous problem of rehabilitating its war-wounded. Professor Max Lange has had great experience treating the German veteran. Now he has undertaken the task of writing this textbook in German, which will be of great value to members of the medical profession in dealing with the veteran and other war-wounded.

Apparently the problems of rehabilitation are the same in Germany as in Veterans Hospitals in the United States. It has been difficult for us to outline routine care. Professor Lange has also found this true, and stresses the importance of considering each case individually. This book is not an attempt to report cases, but contains a description of the principles of orthopaedic and reconstruction surgery. First is a chapter on technique, part of which describes conservative treatment as well. The remaining chapters discuss the various problems and their management. As the result of delayed care, there have been many contractures and deformities. These are discussed in detail. Throughout the book there are numerous drawings, which are very descriptive, and a large number of photographs.

It is a pleasure to congratulate the author on providing a text and reference book for his German colleagues. He has taken an important step in re-establishing the great reputation of medicine in his country.

CEREBRAL PALSY. John F. Pohl, M.D. Saint Paul, Minnesota, Bruce Publishing Company, 1950. $5.00.

The writer, in agreement with most other physicians and therapists who are working with sufferers from cerebral palsy, states in his preface that while many other factors must be considered, "the treatment of cerebral palsy consists of helping the child to help himself". It is certain that when a patient knows how to help himself and can see some boundaries to his great physical limitations, his outlook on life cannot help but be improved.

In this well-organized book, Dr. Pohl sets forth the problem as he sees it, and then takes up in separate chapters the methods of neuromuscular training as applied to the different parts of the body. There are also chapters devoted to speech and occupational therapy. Great strides have been made in this latter field, and trained observers have reported tremendous accomplishments. Dr. Pohl describes clearly the methods which

have been successfully employed, and the actual illustrations of patients engaged in various forms of occupational therapy are excellent. In fact all of the illustrations are very valuable.

At a time when the demand for trained therapists is far exceeding the supply, this concise little book should be of great help to workers in the field. Without "popularizing" the important facts, it is a simple and intelligent treatment of them.

OPERATIVER DAUMENERSATZ UND BESEITIGUNG VON GREIFSTÖRUNGEN BEI FINGERVERLUSTEN (Operative Substitution of the Thumb and Correction of Disturbances of the Hand Grip Due to Loss of Fingers). Prof. Dr. Otto Hilgenfeldt. Stuttgart, Ferdinand Enke, 1950.

This book is the result of the author's personal work during World War II and the post-war period on the reconstruction of the thumb and disturbances of the grip. The preface indicates that the author had no access to the non-German literature on this subject, and apparently had only heard about such books as Bunnell's and Steindler's. It is, therefore, especially interesting to learn the results of his experiences, his clear-cut principles and indications for repair, minute description of surgical technique, and presentation of case reports.

The material is divided into four parts:

The first part presents a good discussion of the principles involved, indications, and anatomy.

The second part is dedicated to the principles of operative treatment for thumb reconstruction. Here rotation osteotomy, finger substitution, splitting, and displacements are considered. An excellent description is given, with illustrations, of the technique of transposition of the middle finger for reconstruction of a thumb. Many illustrative case reports with critical analysis of the results are included. An interesting method of splitting reconstruction with elongation of the thumb ray is described; the details of the technique are well illustrated.

The third part contains a discussion of treatment of hand injuries with preservation of the thumb. Various situations are described.

In the fourth part is a brief discussion of thumb prostheses.

The book will be of much interest and value to the surgeon engaged in reconstruction of the hand.

RETROPOSITION OF LUMBAR VERTEBRAE. Lars Hagelstam. *Acta Chirurgica Scandinavica*, Supplementum 143, 1949.

Retroposition of the lumbar vertebrae is presented on the basis of a study of the roentgenograms of 325 patients with morbid conditions of the lumbar spine. By mere visual inspection of the pictures, ninety-four cases of retroposition were selected. Retroposition of less than two millimeters will escape discovery by visual inspection; accordingly, a method of accurately measuring retroposition has been introduced.

True and apparent retropositions are studied in detail; the causes of apparent retroposition are chiefly faulty roentgenographic technique and differences in the anteroposterior diameters of the subjacent vertebrae. In approximately half of the cases with low-back pain, with or without sciatica, the anteroposterior diameters of the fourth and fifth lumbar vertebrae exceeded those of the subjacent vertebrae by two millimeters or less.

True retroposition was encountered in only two diagnostic groups: cases of low-back pain with or without sciatica and cases of spondylitis, as in tuberculosis or other types of sepsis. The appearance of retroposition in only these two groups indicated to the author that destruction or degeneration of the disc is the primary cause of retroposition.

Instability of the lumbar spine was studied in twelve healthy individuals to compare with those who had back pain or sciatica, either alone or in combination. Some slight instability with displacement of one millimeter or less was observed, and this would seldom be seen by roentgenographic inspection alone. The majority of those with morbid spine conditions had instability of approximately 75 per cent.; displacements of the fifth lumbar vertebra, either forward or backward, up to three millimeters were noted.

Retroposition was observed in all of the lumbar vertebrae, the number of cases decreasing from the fifth lumbar vertebra to the first lumbar; the frequency at the fifth lumbar was about twice that at the fourth lumbar, and about six times that at the third lumbar level. Multiple retropositions in the same case were fairly common.

Pain and objective neurological signs were studied in seventy-four cases. There was no observation to support the conception that pain in these cases is due to the retroposition. The results of these studies indicated that the genesis of pain in retroposition is the same as in other cases,—namely, degeneration, with or without herniation of the disc.

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ADDRESSES OF CONTRIBUTORS

OCTOBER 1950

KARL S. ALFRED, M.D., University Hospitals of Cleveland, 2065 Adelbert Road, Cleveland 6, Ohio.
LENOX D. BAKER, M.D., Duke Hospital, Durham, North Carolina.
JOSEPH S. BARR, M.D., 234 Marlborough Street, Boston 16, Massachusetts.
W. COMPERE BASOM, M.D., 520 Montana Street, El Paso, Texas.
CHARLES O. BECHTOL, M.D., 1624 Franklin Street, Oakland 12, California.
EDGAR M. BICK, M.D., 30 East 60th Street, New York 22, N. Y.
HARRY C. BLAIR, M.D., Standard Insurance Building, Portland 5, Oregon.
COLONEL E. A. BRAV, M.C., Letterman Army Hospital, San Francisco, California.
LOUIS W. BRECK, M.D., 520 Montana Street, El Paso, Texas.
BRANDON CARRELL, M.D., 3701 Maple Avenue, Dallas 4, Texas.
R. W. COONRAD, M.D., Georgia Warm Springs Foundation, Warm Springs, Georgia.
JOSEPH W. COPEL, M.D., Mount Sinai Hospital, New York 29, N. Y.
EDWARD J. COUGHLIN, JR., M.D., Spring Street, Williamstown, Massachusetts.
JOE B. DAVIS, M.D., Standard Insurance Building, Portland 5, Oregon.
THOMAS L. DELORME, M.D., 12 Rustlewood Road, Milton 87, Massachusetts.
Z. B. FRIEDENBERG, M.D., 133 South 36th Street, Philadelphia 4, Pennsylvania.
BARRY FRIEDMAN, M.D., 2460 Fairmount Boulevard, Cleveland Heights, Ohio.
DELLIVAN M. FUIKS, M.D., 1515 28th Street, Sacramento 16, California.
HERMAN GLADSTONE, M.D., 215 East 79th Street, New York 21, N. Y.
CHARLES E. GRAYSON, M.D., 1215 28th Street, Sacramento 16, California.
HOWARD T. GUARE, M.D., Bennington, Vermont.
COMMANDER WILLIAM H. GULLEDGE, M.C., Naval Hospital, Arèa, Hawaii.
G. EDMUND HAGGART, M.D., Lahey Clinic, 605 Commonwealth Avenue, Boston 15, Massachusetts.
HALFORD HALLOCK, M.D., 1 East 63rd Street, New York 21, N. Y.
ALLEN E. HAMBURG, M.D., Staff House, Medical Center, Jersey City, New Jersey.
MAXWELL HARBIN, M.D., 10515 Carnegie Avenue, Cleveland 6, Ohio.
MAJOR GEORGE J. HAYES, M.C., Chief, Neurosurgical Section, Walter Reed General Hospital, Washington, D. C.
CHARLES H. HERNDON, M.D., University Hospitals of Cleveland, 2065 Adelbert Road, Cleveland 6, Ohio.
CLARENCE H. HEYMAN, M.D., 10515 Carnegie Avenue, Cleveland 6, Ohio.
WILLIAM W. HOWE, JR., M.D., Professional Building, Rochester 4, New York.
W. A. HOYT, JR., M.D., 175 South Main Street, Akron 8, Ohio.
ROBERT J. JOPLIN, M.D., 1180 Beacon Street, Boston 46, Massachusetts.
EMANUEL B. KAPLAN, M.D., 1001 Grand Concourse, New York 52, N. Y.
J. ALBERT KEY, M.D., 4952 Maryland Avenue, St. Louis 8, Missouri.
THOMAS LACEY, II, M.D., Strong Memorial Hospital, Rochester 7, New York.
MORTON H. LEONARD, M.D., 520 Montana Street, El Paso, Texas.
LYON K. LOOMIS, M.D., 1140 Maison Blanche Building, New Orleans 16, Louisiana.
HERBERT S. LOSEFF, M.D., 6622 Glenwood Avenue, Chicago 26, Illinois.
ABRAHAM J. MOSKOVITZ, M.D., Bennington, Vermont.
HARLAN W. MOSSMAN, PH.D., Department of Anatomy, University of Wisconsin, Madison 6, Wisconsin.
DON H. O'DONOGHUE, M.D., 609 Medical Arts Building, Oklahoma City, Oklahoma.
LEONARD T. PETERSON, M.D., 915 Nineteenth Street, N.W., Washington 6, D. C.
IGNACIO V. PONSETI, M.D., Department of Orthopedic Surgery, State University of Iowa, Iowa City, Iowa.
MOSES RABSON, M.D., 2816 South Seventh Street, Philadelphia 48, Pennsylvania.
ROBERT H. RAMSEY, M.D., Barnes Hospital, 600 South Kingshighway, St. Louis 10, Missouri.
ROBERT J. REEVES, M.D., Duke Hospital, Durham, North Carolina.
JOHN A. REIDY, M.D., 1101 Beacon Street, Brookline 46, Massachusetts.
WILLIAM M. ROGERS, PH.D., 630 West 168th Street, New York 32, N. Y.
HERMAN L. RUDOLPH, M.D., 400 North Fifth Street, Reading, Pennsylvania.
R. PLATO SCHWARTZ, M.D., 260 Crittenden Boulevard, Rochester 7, New York.
WILLIAM BEECHER SCOVILLE, M.D., 85 Jefferson Street, Hartford 6, Connecticut.
FRANK L. SHIPP, M.D., Lahey Clinic, 605 Commonwealth Avenue, Boston 15, Massachusetts.
WILLIAM J. SHRIBER, M.D., 770 Centre Street, Jamaica Plain 30, Massachusetts.
MRS. SARAH SPECTOR, Mount Sinai Hospital, New York 29, N. Y.
DANIEL M. STIEFEL, M.D., 1563 David Whitney Building, Detroit 26, Michigan.
ALLAN J. STINCHFIELD, M.D., 56 Hospital Street, Augusta, Maine.
FRANK E. STINCHFIELD, M.D., 180 Fort Washington Avenue, New York 32, N. Y.
FRANCIS E. WEST, M.D., 910 Medico Dental Building, San Diego, California.
BARNES WOODHALL, M.D., Department of Surgery, Duke University School of Medicine, Durham, North Carolina.
J. W. WOODWARD, M.D., Amicable Building, Waco, Texas.

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